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Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Regional Sediment Management Program

Sediment Budget for the Indiana Shore from Michigan City Harbor to Burns Waterway Harbor

Andrew Morang, Ashley E. Frey, David F. Bucaro,
Sara Brodzinsky, and Jeff A. Fuller

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Abstract

Net sediment transport in the littoral cell extending from Michigan City Harbor to Burns Waterway Harbor, IN, is from east to west. For the four decades following construction of the harbor (approximately 1966-2010), net littoral transport averaged about 194,000 yd^3/year (115,000 + 79,000). Of this amount, accumulation in the fillet east of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead was about 115,000 yd^3/year. These results are based on analysis of cross-shore beach profiles, reprocessed from paper records and electronic files. Dredging from the NIPSCO Bailly Generating Station cooling water intake was 79,000 yd^3/year (2,366,000 yd^3 ÷ 30 years). The total transport calculated in this study is higher than most published previous estimates.

The volume of sediment now bypassing the lakeward end of the bulkhead and entering the Federal harbor is estimated to be 86,000 yd^3/year. This value is based on the proportion of the active zone beyond the lakeward (northern) end of the Arcelor-Mittal bulkhead (194,000 × 0.443). This value will have to be confirmed with dredging statistics in the future.

A ship grounding in April, 2012, demonstrated that the approach channel east of Burns Waterway Harbor is significantly shallower than shown on hydrographic charts. This supports the hypothesis that significant sand is bypassing the lakeward end of the Arcelor-Mittal bulkhead rather than being trapped in the fillet.

An average of 73,000 yd^3/year of sand has been placed west of Portage/ Burns Waterway (Burns Ditch) (1,829,000 total from both the fillet and the Portage/Burns Waterway ÷ 25 years). Most sand has been placed in shallow water offshore of the town of Ogden Dunes, and some was placed directly on the beach at the National Park Service Portage Lakefront Park property. Full bypassing needs to be about three times this amount if it is to match the longshore transport value of 194,000 yd^3/year.

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Preface

This study was conducted for U.S. Army Engineer District, Chicago under Project Number 336183, “Lower Lake Michigan/Indiana Sediment Budget.” The technical monitor was Linda Lillycrop.

The work was performed by the Coastal Engineering Branch (HN-C) of the Navigation Division (HN), U.S. Army Engineer Research and Development Center – Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Dr. Jeffrey Waters was Branch Chief, CEERD-HN-C; Dr. Rose Kress was Division Chief, CEERD-HN, and Jeff Lillycrop was the Technical Director for Navigation Research Area. The Deputy Director of ERDC-CHL was Jose Sanchez and the Director was Dr. William Martin.

The USACE’s Regional Sediment Management (RSM) Lower Lake Michigan/ Indiana initiative funded this study. The RSM program also supported publication of this report.

Stephen Davis, Indiana Department of Natural Resources, Division of Water, provided scanned copies of survey notes and cross-shore profiles and thoroughly reviewed this report. Dr. Jeffrey Waters, CHL, ERDC, Dr. Harley Winer, USACE (retired), and Linda Lillycrop, CHL, ERDC, also reviewed this report.

Shanon Chader and Michael Mohr, USACE Buffalo District, provided data computed during an earlier study. James Keen, CHL, ERDC, digitized the 1960s and 1970s profiles and scanned many of the 1960s aerial photographs. Mckenzie Pollock, CHL, ERDC, scanned other photographs from the Beach Erosion Board archives. Mark Graves, Environmental Laboratory, ERDC, provided use of a large-format scanner for the 18×18 inch photographic prints. Paul Szempruch, USAE District, Galveston, computed shoreline parameters and assisted with some of the analyses.

COL Kevin Wilson was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards (yd^3)	0.7646	cubic meters (m^3)
feet	0.3048	meters
inches	2.540	centimeters
miles (U.S. statute)	1.6093	kilometers
tons (short)	0.9078	tons (metric)

1 Introduction

In October 2010, U.S. Army Corps of Engineers (USACE) District, Chicago (LRC), via the Dredging Operations Technical Support Program (DOTS), requested assistance from the Coastal and Hydraulics Laboratory (CHL), Engineer Research and Development Center (ERDC), in planning a Feasibility Study to evaluate coastal processes, sedimentation response, dredging, and maintenance issues at Burns Waterway Harbor, Indiana (Figures 1 and 2). In response to the DOTS request, CHL prepared a letter report after conducting a site visit and evaluating data and analysis needs. The main recommendation of the letter report was to develop a sediment budget around the Burns Waterway Harbor. Following this recommendation, LRC and CHL conducted an analysis of sediment processes along the Indiana shore and calculated a sediment budget. This work was funded through the USACE Regional Sediment Management (RSM) Lower Lake Michigan/Indiana initiative.

Shoreline changes along the Indiana coast have been a concern for the USACE, the National Park Service, Indiana Department of Natural Resources, the Town of Ogden Dunes, and other municipal and private entities in the study area since the 1960s. The Burns Waterway Harbor project was controversial for decades before construction began in the 1960s, and the USACE was well aware of potential littoral disruptions for this area. USACE studies clearly warned of possible sediment issues, and in the Congressional Authorization, the State of Indiana had to provide assurances of local cooperation. One specific item of local cooperation stated: "to hold and save the United States free from damage due to construction and maintenance of the project, including damages resulting from any shore erosion that may occur." Readers interested in details should consult the voluminous authorization documents and studies from the 1960s.

Burns Waterway Harbor is located within a longshore littoral drift system that results in the net westward movement of sediment and sand. The project area includes, from east to west (USACE Chicago 2010):

1. The Indiana Dunes National Lakeshore (INDU);
2. Bailly Generating Station (BGS), owned by the Northern Indiana Public Service Company (NIPSCO);

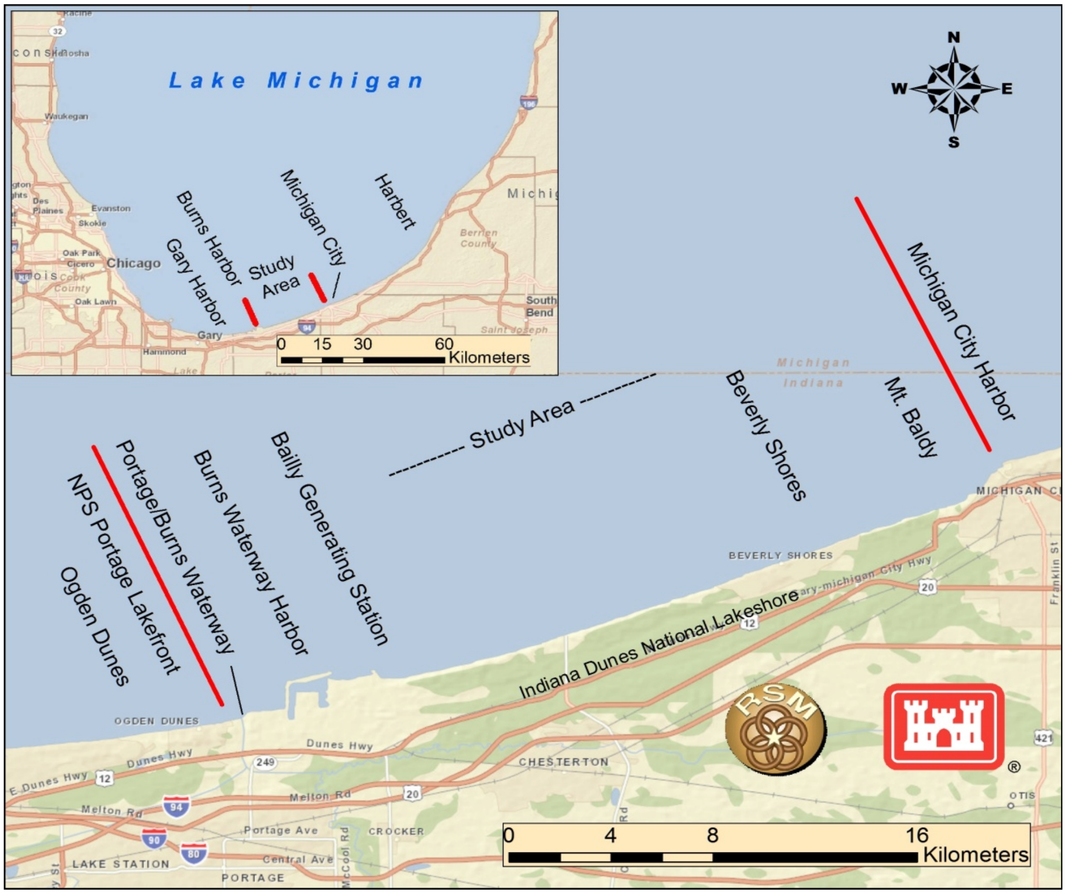

Figure 1. Study area, southern Lake Michigan. Background from ESRI maps and data.

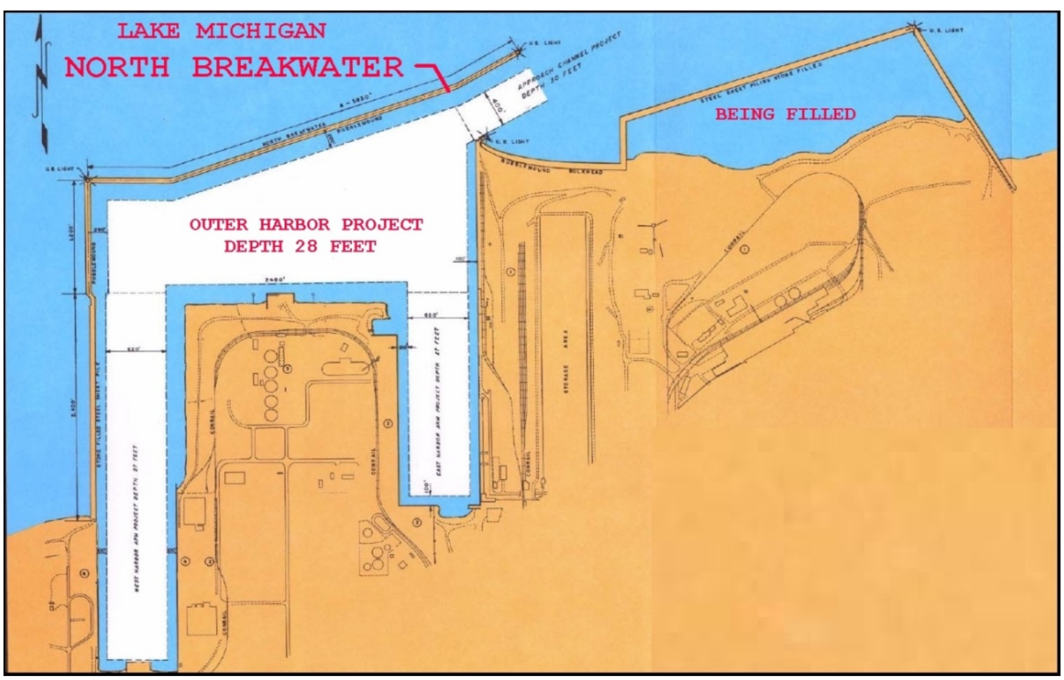

Figure 2. Burns Waterway Harbor (at west) and Arcelor-Mittal commercial bulkhead at east side of complex. Map modified from USACE Chicago web page. Area on east behind bulkhead was never completely filled.

3. Burns Waterway Harbor and associated structures which comprise the International Port of Indiana;
4. US Steel – Midwest Plant;
5. Burns Small Boat Harbor at the mouth of Portage/Burns Waterway;
6. A second segment of the INDU at Portage Lakefront Park;
7. The beach at the community of Ogden Dunes.

Burns Waterway Harbor is a federally maintained deep draft commercial harbor consisting of a 27-ft deep harbor channel, a 28-ft deep outer harbor channel, a 30-ft deep approach channel and 5,800 ft of rubblemound breakwater protecting the harbor channel. Burns Small Boat Harbor is a federally maintained recreational harbor consisting of an 11-ft deep channel and 1,600 ft of breakwater protecting small craft using Portage/Burns Waterway for access to Lake Michigan (USACE Chicago 2010).

Net longshore sediment transport between Michigan City Harbor and Burns Waterway Harbor is to the southwest. Burns Waterway Harbor forms the southwest end of a littoral cell and acts as a barrier to sediment moving southwestward (Figure 3). Sediment has been accreting against the easternmost Arcelor-Mittal (formerly Bethlehem Steel) bulkhead since project construction in the 1960s, elevating the lake bottom around the offshore NIPSCO BGS water intake structure. This sand accumulation has required dredging at irregular intervals, recently every two to three years, to prevent the intake from being clogged.

Figure 3. Fillet area east of NIPSCO Bailly Generating Station (BGS), October 16, 2010. The water in the lower right is the warm water outfall.

In 2007 and 2008, sand had to be dredged from the federal Burns Waterway Harbor after a non-dredge interval of a decade. This indicates that the impoundment east of the Arcelor-Mittal bulkhead has filled enough that sand is now moving around the structure and entering the

federal harbor further to the west (Figure 2). Dredging volumes are summarized in the USACE 905(b) Reconnaissance Report (USACE Chicago 2010) and tabulated later in this report. The Burns Waterway Harbor Shoreline Damage Mitigation Reconnaissance Study provides more in-depth background on sediment issues, summarizes public concerns, and lists previous studies (USACE Chicago 2010).

West of the Burns Waterway Harbor, the Town of Ogden Dunes has experienced erosion and the National Park Service (NPS) is concerned about erosion on NPS property immediately west of the Burns Small Boat Harbor and east of Ogden Dunes (the Portage Lakefront Park), and west of Ogden Dunes at the INDU “West Beach Unit.”

The Reconnaissance Study (USACE Chicago 2010) recommends that a Feasibility Study be conducted to investigate alternative plans to mitigate for the impacts of federal navigation structures on the shoreline east and west of Burns Waterway Harbor. The 905(b) Reconnaissance Report was approved by the Great Lakes and Ohio River Division of the USACE in November 2010. By incorporating goals of Regional Sediment Management (RSM; Lillycrop et al. 2011), sediment will be treated as a resource to benefit the entire system rather than as a nuisance to be eliminated regardless of the consequences on the coastal environment. Managing sediment to benefit a region potentially saves money, allows use of natural processes to solve engineering problems, and improves the environment. One of the important elements in implementing RSM along the Lake Michigan shore is to develop a sediment budget for the purposes of:

1. Gaining a better understanding of coastal processes in the area;
2. Identifying effects of harbor structures on these processes;
3. Identifying sources, sinks, and pathways of sediment.

This analysis of coastal processes covers the reach between Michigan City Harbor and Burns Waterway Harbor, including the Indiana Dunes National Lakeshore, beachfront owned by NIPSCO east of Burns Waterway Harbor, the bulkhead at the Arcelor-Mittal Steel Company (formerly Bethlehem Steel Company, and later International Steel Group (ISG)), the federal Burns Waterway Harbor, and Burns Small Boat Harbor. This report summarizes the results of the sediment budget developed by CHL and LRC and also describes:

1. Data sources applicable to the study area;
2. Processing and georeferencing historical aerial photographs;
3. Recovery of cross-shore profile surveys and data analysis;
4. Assumptions and limitations;
5. Recommendations for continued refinement.

Another purpose of this report is to document and compile in one place information pertinent to historical surveys along the south Lake Michigan shoreline as a resource for future researchers. Most units in this report will be stated in English units, in correspondence with original data collection and with contemporary use for dredging volumes (yd^3).

2 Study Area and Physical Processes

2.1 Burns waterway harbor

Burns Waterway Harbor (also known as Burns Harbor, Burns International Harbor, International Port of Indiana, or Port of Indiana) is located in Porter County, Indiana. Construction and improvement of the harbor was authorized by the River and Harbor Act of 1965. The harbor includes 2,400 ft of non-federal steel sheet pile breakwater to the west connected to 5,830 ft of federally constructed rubblemound breakwaters to the west and north. The navigation elements include a 30-ft deep by 400 foot wide approach channel, a 28 f-t deep outer harbor basin, and two 27-ft deep by 620-ft wide east and west harbor arms (Figure 2). The east side of the harbor complex includes rubblemound bulkhead constructed by the Bethlehem Steel Company (now owned by Arcelor-Mittal). The bulkhead, authorized under Department of the Army permits from August 25, 1966, and October 26, 1966, enclosed an area of about 300 acres, of which over half was eventually filled with available materials (sand from former sand dunes and slag (the vitreous residue left after smelting ore)).

USACE Chicago (2010) summarized the history of the NIPSCO Bailly Generating Station (hereafter called BGS) and the Burns Waterway Harbor:

> BGS was constructed in 1961 and opened in 1962 with a single boiler generating electricity. A second boiler was added in 1968, increasing the station's capacity. As part of the generating process, the equipment is cooled by a cold water circulating system. Water is supplied at an offshore intake well, circulated through the plant, and returned to the lake at the shoreline though a discharge flume. The intake well was designed and constructed at a depth of 21 ft below LWD[1], with 36 inch diameter feeder pipes installed at a depth of 17 ft around a circular stone well. Water is pumped to the circulating system through two 14-ft diameter pipes with inlets at the center of the well. Intake rates range from 175,000 to 350,000 gallons per minute.
>
> The International Port of Indiana was developed soon after BGS began operations. Midwest Steel, a Division of National Steel (now

[1] LWD = low water datum, or 577.5 ft International Great Lakes Datum (IGLD) of 1985.

U.S. Steel), received a permit from the USACE in 1961 to construct a bulkhead extending into the lake. The bulkhead was never completed, but the portion that was constructed, a jetty at the mouth of Burns Waterway, was built in 1967. Bethlehem Steel (now Arcelor-Mittal Steel) received a permit from the USACE to construct a bulkhead enclosing 300 acres west of the BGS shoreline in 1966. The bulkhead was constructed in 1968. Burns Waterway Harbor was constructed by the State of Indiana using a USACE approved design, as authorized by the River and Harbor Act of 1965 (P.L. 89-298). Design of the federal channel and breakwaters took into account the planned and partially constructed Bethlehem Steel and Midwest Steel structures. The Federal Channel is protected by both the private structures and the federal breakwaters. Without the presence of the Bethlehem Steel bulkhead, it is likely that a federal breakwater east of the channel would have been necessary, resulting in additional construction and maintenance costs to the federal government. The rubblemound breakwater was completed in 1968 and the Chicago District took over maintenance of the completed harbor in 1972. Reimbursements to the State of Indiana were completed in 1975. As required in the authorizing legislation, reimbursements were provided upon approval of the completed project by the Chief of Engineers.

2.2 Sediments and littoral transport

Geomorphically, much of the south shore of Lake Michigan consists of sandy beach with sand dunes and marshes inland and mixed sand and clay lakebed offshore. The southwest end of the lake close to Gary and South Chicago has been extensively developed or urbanized, greatly altering the original surface morphology. Even in less-developed areas, many of the dunes were mined for sand in the early 20th century (USACE Buffalo 2008). For example, a parabolic dune named “Hoosier Slide” in Michigan City, which once exceeded Mt. Baldy (currently about 125 ft above lake level) in size, is gone. The Ball Company of Muncie, Indiana, mined the quartz sand and made canning jars from the material (KellerLynn 2010). In addition, dunes in the Long Lake area west of Ogden Dunes (now in the INDU West Beach Unit) were mined and the sand was transported to Chicago, where it became lakefront fill prior to and after the 1893 World’s Fair. The remaining dunes, marshes, and forests have been incorporated into two public preserves whose mission is to preserve the natural habitat, the Indiana Dunes National Lakeshore and the Indiana Dunes State Park (Figure 4).

Figure 4. Indiana Dunes State Park, July 17, 2011, view looking northwest. In this area, dunes have been preserved in more or less their original condition, and the area is an important ecological and recreational resource.

Most creeks or rivers supply minimal sediment to the coast in this region. The exception is the Portage/Burns Waterway, which receives bank erosion sediment from the east and west arms of the Little Calumet River, which converge and flow to Lake Michigan via the Waterway. Sediment dredged from the Portage/Burns Waterway has been used to protect the shore at Ogden Dunes in the 1980s and 2000s (volumes discussed later).

Sand on southern Lake Michigan beaches historically was supplied from bluff and lake bed erosion and, to a lesser degree, intermittent stream input (Shabica and Pranschke 1994). Bluffs with elevations up to 80 ft along the Illinois and Michigan shores were likely the primary contributor of sand to the southern beaches. But since the mid-late-1800s, bluffs along the Illinois lakeshore have been protected with steel, concrete, and stone armor. Compounding the problem, structures like the jetties and breakwaters at Waukegan, Great Lakes, Wilmette, and Chicago in Illinois and Indiana Harbor and Ship Canal in East Chicago, Indiana, almost totally interrupted the movement of sediment to the south. Much of the southwest Illinois shore, essentially all of Chicago, is now armored or artificial. On the

Michigan shore, bluffs have been less armored than in Illinois, but sand from this source has also largely been interrupted by jetties at St. Joseph, New Buffalo and Michigan City Harbor. Shabica and Pranschke (1994) report that nearshore lakebed erosion, which historically provided 20 to 40 percent of the new sand to the system, will soon become the primary source of sand for the southern beaches.

Net longshore transport in the Michigan City area is from north to south. W.F. Baird & Associates (2004) computed potential longshore transport for the Michigan City area using a proprietary processed-based numerical model called COSMOS. Based on a sand size of 0.3 mm, wave data was transformed inshore to 15 m (50 ft) water depth to compute transport for a 45-year period from 1956 to 2000. Although net southward transport was predominant, a major variation in net transport occurred every 3- 5 years. Variations were attributed to periodicities of the synoptic scale and meso-scale weather systems that affect Lake Michigan. Over the 45 years, potential average southward transport was 500,000 yd^3/year, while average northward transport was 210,000 yd^3/year. The net annual computed transport at Michigan City was 290,000 yd^3 to the south for the selected 45-year period. The authors reported that there was good agreement between the historical net transport rate prior to harbor construction and the infilling rate for the updrift (north) fillet. There is no significant bypassing of sediment around Michigan City from south to north during west storms, but from north to south, W.F. Baird & Associates (2004) concluded that about 99,400 yd^3/year naturally bypasses the shoal offshore of the offshore harbor breakwater. In this Burns Harbor sediment budget study, we have not re-examined morphological data from the Michigan City area and will use the Baird value for subsequent calculations.

The coast between the Michigan City Harbor and Burns Waterway Harbor has been generally recessional during the 20th century, with dune-bluff recession and shoreline erosion near the northeast end of the reach at Mt Baldy being the highest on the Indiana coast ("Conditions along the Indiana Coastline," http://www.in.gov/nrc_dnr/lakemichigan/coadyn/coadync.html, accessed May 16, 2012). A steel sheet pile seawall with stone toe protection protecting the NIPSCO property prevents erosion immediately downdrift of the Michigan City Harbor. But with the harbor blocking significant sediment movement and the presence of the seawall, the zone of high erosion has been transferred further downdrift, to the areas of Crescent Dune and Mount Baldy in the Indiana Dunes National Lakeshore. Erosion rates gradually

decrease westward. In 1974, 13,000 ft of rock revetment was constructed along the Town of Beverly Shores to protect Lake Front Drive (Figure 1). Just west of Mt. Baldy, W.F. Baird & Associates (2004) computed net longshore transport to be 247,000 yd^3/year to the west. This is the Cosmos-computed transport, which may be greater than the available sediment sources: bypassing at Michigan City Harbor, beach nourishment at Mt Baldy, and shoreline and dune loss. This value of 247,000 yd^3/year has not been used in this study.

At Burns Waterway Harbor, Sargent and Lundy (1978) reported longshore transport to be 80,000 yd^3/year. This was based on the transport value at Michigan City, from the *Shore Protection Manual* (1973). Wood et al. (1990) estimated 75,500 yd^3/year to the west based on wave modeling. USACE Chicago (2010) cited estimates ranging from around 50,000 to 80,000 yd^3/year for net littoral movement at Burns Waterway Harbor. Note these volumes are significantly lower than the W.F. Baird Cosmos-calculated value for the Mt. Baldy area.

Proceeding west, the next section of coast is bounded by Burns Waterway Harbor on the east and the United States Steel revetment at Gary on the west. Wood and Davis (1986) documented how Burns Waterway Harbor had blocked essentially all littoral drift, resulting in severe erosion along the Midwest Steel property immediately downdrift (west) of the federal harbor. In addition, the east jetty of the Portage/Burns Waterway (Burns Ditch) trapped some sand removed from the Midwest Steel shore, thereby transferring the erosion area further down the coast to the community of Ogden Dunes. Based on an analysis of aerial photographs, they documented that the highest sediment loss was in the east portion of the reach near Burns Waterway Harbor, while moderate to high gain rates occurred in the western portion near Marquette Park and Gary Harbor.

3 Previous Studies

Burns Waterway Harbor has been controversial since well before its construction in the mid-1960s. Several studies have examined sand accretion at the NIPSCO BGS cooling water intake and erosion of the lakeshore west of the Harbor. The list below is adapted from USACE Chicago (2010):

1. Great Lakes Harbors Study – Interim Report on Burns Waterway Harbor, Indiana; USACE; 1963. This report was the basis for the authorization of Burns Waterway Harbor in 1965.
2. Water Intake Study, Bailly Generating Station; Sargent & Lundy 1978. This study, commissioned by NIPSCO, examined littoral processes affecting the BGS cold water intake and evaluated alternatives for preventing sand from entering the station's cold water circulating system.
3. Water Intake Conceptual Design Study, Bailly Generating Station; Sargent & Lundy 1978. This study examined in detail the feasibility and cost of extending the intake well to deeper water and of dredging around the intake structure.
4. Indiana Shoreline Erosion Feasibility Study; USACE 1982. This study examined coastal processes and shoreline erosion from Michigan City, Indiana to the Indiana/Illinois state line. The study recommended beach nourishment of the IDNL at Mount Baldy, west of Michigan City Harbor and to the east of Burns Waterway Harbor.
5. Burns Waterway Small Boat Harbor, Indiana: Final Detailed Project Report; USACE 1983. The evaluation of plans to construct a small boat harbor at the mouth of Burns Waterway included an analysis of littoral drift patterns in the study area.
6. Evaluation of Alternative Solutions for the Circulating Water System Problems Caused by Dune Grass and Sand, Bailly Generating Station; NIPSCO 1983. NIPSCO's Engineering Department evaluated various alternatives to address ongoing problems caused by sand and dune grass entering the circulating system.
7. Study of Intake Dredge Alternatives; Harza Engineering 1988. This study, commissioned by NIPSCO, evaluated alternatives to minimize the effect of accumulated sand on the BGS cold water circulating system.
8. Burns Waterway Small Boat Harbor Monitoring Program, Portage County, Indiana, Final Report; USACE 1995. This report summarized the findings

of a program instituted to monitor the effects of the construction of Burns Small Boat Harbor on the nearby shoreline.

9. Northern Indiana Public Service Company Bailly Generating Station Circulating Water System Study; Black & Veatch Engineering 1996. This study, commissioned by NIPSCO, reexamined measures to address accumulation of sand at the BGS intake.
10. Engineering Study of Bailly Station Intake; Harrington Engineering & Construction 1999. This study evaluated alternatives for relocation or rehabilitation of the BGS intake.
11. Combined Coastal Program Document and Final Environmental Impact Statement for the State of Indiana; Office of Ocean and Coastal Resource Management National Oceanic and Atmospheric Administration and Indiana Department of Natural Resources, 2002. Appendix G of this report discussed coastal processes affecting Indiana's Lake Michigan shoreline.
12. Draft Evaluation of Dredged Material Management Plans for Michigan City, Prepared for USACE Detroit District; Baird & Associates, 2004. This report discussed regional sediment patterns along the Indiana and Michigan shorelines, including the shoreline east of Burns Waterway Harbor.
13. Indiana Shoreline Monitoring: Burns International Harbor to Michigan City Harbor; USACE, 2008. This report studied littoral patterns between Michigan City Harbor and Burns Waterway Harbor and focused, in particular, on USACE beach nourishment activities just west of Michigan City Harbor.
14. Value Engineering Study on the Northern Indiana Public Service Company Bailly Water Intake Structure Dredging; USACE, 2008. This study evaluated the cost effectiveness of various alternatives to current dredging practices at the BGS intake.
15. Coast Week Field Talk; Indiana Department of Natural Resources, 2009. This presentation covered the effects of structures associated with Burns Waterway Harbor and Burns Small Boat Harbor on the shoreline at BGS, the INDU, and the community of Ogden Dunes.
16. NIPSCO Bailly Warm Water Discharge Flow Direction Change across the Beach; Indiana Department of Natural Resources, 2009. This presentation covered the effects of littoral accretions at BGS on Lake Michigan current patterns and the resulting flow change in the BGS circulating system's discharge.

4 Data Sources, Management, and Organization

4.1 Software

Spatial data was organized and displayed in ESRI® ArcMap™ Geographic Information System (GIS) software, version 9.3.1 or 10.0. Data was projected in Universal Transverse Mercator (UTM) Zone 16N, North American Datum 1983, with units in meters. Features specifically related to an elevation (for example, +2 ft low water datum (LWD) shoreline position) are referenced to International Great Lakes Datum (IGLD) of 1985 (Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data 1992).

Cross-shore profiles were plotted in the Regional Morphology and Analysis Package (RMAP) software, version 3.2 (Morang et al. 2009).

Note on units: Cross-shore profile data has been left in units of feet as it was originally plotted, with elevations related to low water datum (LWD) IGLD1955. The plots were not converted to IGLD1985 because comparisons and volume calculations are independent of datum as long as all elevation data are consistent. Dredge volumes have been reported in cubic yards, as per common usage for dredging and engineering projects in this area.

4.2 Aerial photography contemporary

Contemporary aerial photography of southern Lake Michigan and the surrounding states is available online from ESRI® Maps and Data via the ArcGIS Map service. The photography is dynamically scaled as needed. For the project area, maximum resolution was 30 cm (≈13 in). The exact date is not provided in the metadata, but tree cover and other features resemble those on 2010 and 2011 photography displayed by Google Earth Pro. All historical aerial photography was georeferenced using this online photography as the base. The following text from ESRI® describes the online data:

> This map presents low-resolution imagery for the world and high-resolution imagery for the United States and other areas around the world. The map includes NASA Blue Marble: Next Generation

500m resolution imagery at small scales (above 1:1,000,000), i-cubed 15 m eSAT imagery at medium-to-large scales (down to 1:70,000) for the world, and USGS 15 m Landsat imagery for Antarctica. The map also includes i-cubed Nationwide Prime 1 m or better resolution imagery for the contiguous United States, Getmapping 1 m imagery for Great Britain, and GeoEye IKONOS 1m resolution imagery for Hawaii, parts of Alaska, and several hundred metropolitan areas around the world. I-cubed Nationwide Prime is a seamless, color mosaic of various commercial and government imagery sources, including Aerials Express 0.3 to 0.6m resolution imagery for metropolitan areas and the best available United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) imagery and enhanced versions of United States Geological Survey (USGS) Digital Ortho Quarter Quad (DOQQ) imagery for other areas. For more information on this map, visit us online at http://goto.arcgisonline.com/maps/World_Imagery.

Color orthophotographs from March-April 2005 were also downloaded from the Indiana Spatial Data Portal (http://www.indiana.edu/~gisdata/, accessed March 7, 2012). The portal serves aerial photography from 2005-2010 in GeoTIF and MrSID format.

4.3 Aerial photography historical

The USACE photographed the southern Lake Michigan shore between approximately Gary Harbor, IN, and Harbert, MI, annually from 1966 to 1973 (Table 1). These flights correspond to the time of the Coastal Engineering Research Center (CERC) cross-shore profile surveys and were probably related to that study and to construction of Burns Waterway Harbor. Some prints have cross-shore lines drawn on them with annotations. The prints were stored in the archives of the Beach Erosion Board (BEB), now at CHL in Vicksburg, Mississippi (Morang 2003). Flights from 1966 to 1971 were monochrome, while 1973 was full color. Table 2 lists scanning parameters. Figures 5 and 6 are mosaics of the June 28, 1969, and December 2, 1973, flights. These BEB photography digital files will be distributed by LRC.

Other historical photographs can be downloaded from the Indiana Geological Survey's (IGS) "LakeRim" web page (http://lakerim.indiana.edu/viewer.htm, accessed May 29, 2012). March, 2005 orthophotographs were used in this study.

Table 1. South Lake Michigan aerial photography, USACE Beach Erosion Board archives.

Date	Print size (in)	Coverage	No. frames	Geo-referenced[1]
4-Nov-1966	9×9 and 18×18	Ogden Dunes to Harbert, MI	39	Yes
15-Apr-1967	18×18	Gary to Harbert	35	
4-Dec-1967	18×18	Gary to Harbert	37	
5-Jun-1968	18×18	Gary to Harbert (some frames missing)	22	
28-Jun-1969	18×18	Gary to Warren Dunes, MI	45	Yes
7-May-1970	18×18	Gary to Warren Dunes	73	Not scanned[2]
7-Apr-1971	9×9 and 18×18	Gary to Warren Dunes-Weko Beach, MI	45	Yes
15-Nov-1971	18×18	Gary to Harbert	37	Not scanned[2]
5-May-1972	9×9	Gary to New Buffalo, MI	72	Not scanned[2]
28-Nov-1972	9×9	Ogden Dunes to New Buffalo	60	Not scanned[2]
2-Dec-1973	9×9 (color)	Gary to Harbert	37	Yes

Notes:

Prints from archives of the USACE Beach Erosion Board, now at the Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Vicksburg, MS

Some flights were not georeferenced because shoreline status was not greatly changed from preceding or following dates.

Not scanned because of similarity with previous and later photography; available for future use.

Table 2. Aerial photography scanning parameters.

Print size (in)	Scanner	Resolution (dpi)	Bit depth	TIFF file size (mb)
9×9 monochrome	Epson Expression 10000 XL with Silverfast Ai scan software	1000×1000	16 monochrome	150
18×18 monochrome	HP Designjet Scanner 4200	400×400	8 monochrome	60
9×9 color	Epson Expression 10000 XL with Silverfast Ai scan software	1000×1000	16 color	230

Notes:

Contrast adjusted and borders cropped as needed using Adobe Photoshop Elements version 8 software

4.4 Cross-shore beach profiles

4.4.1 Survey locations/monuments

During the 1960s and early 1970s, the USACE collected cross-shore beach profiles along the Indiana shore. These were called the CERC lines (after the Coastal Engineering Research Center) and the beach locations were numbered CERC1, near Marquette Park, to CERC18, near Michigan City Harbor (Figures 7 and 8). The locations of the profiles were recorded and described in field notebooks but never monumented with permanent

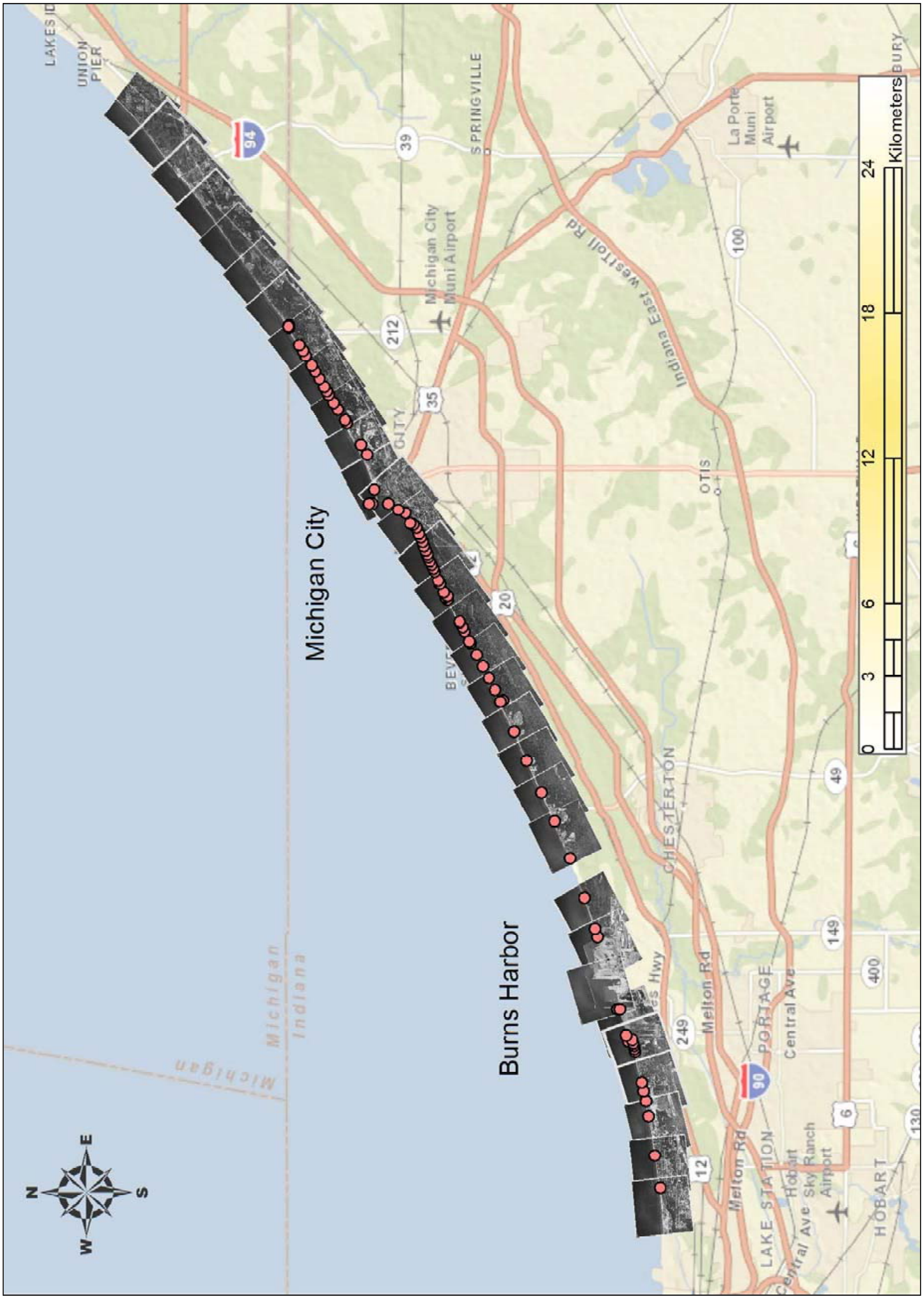

Figure 5. June 28, 1969 aerial photography coverage. Points along shore show profile survey origin locations.

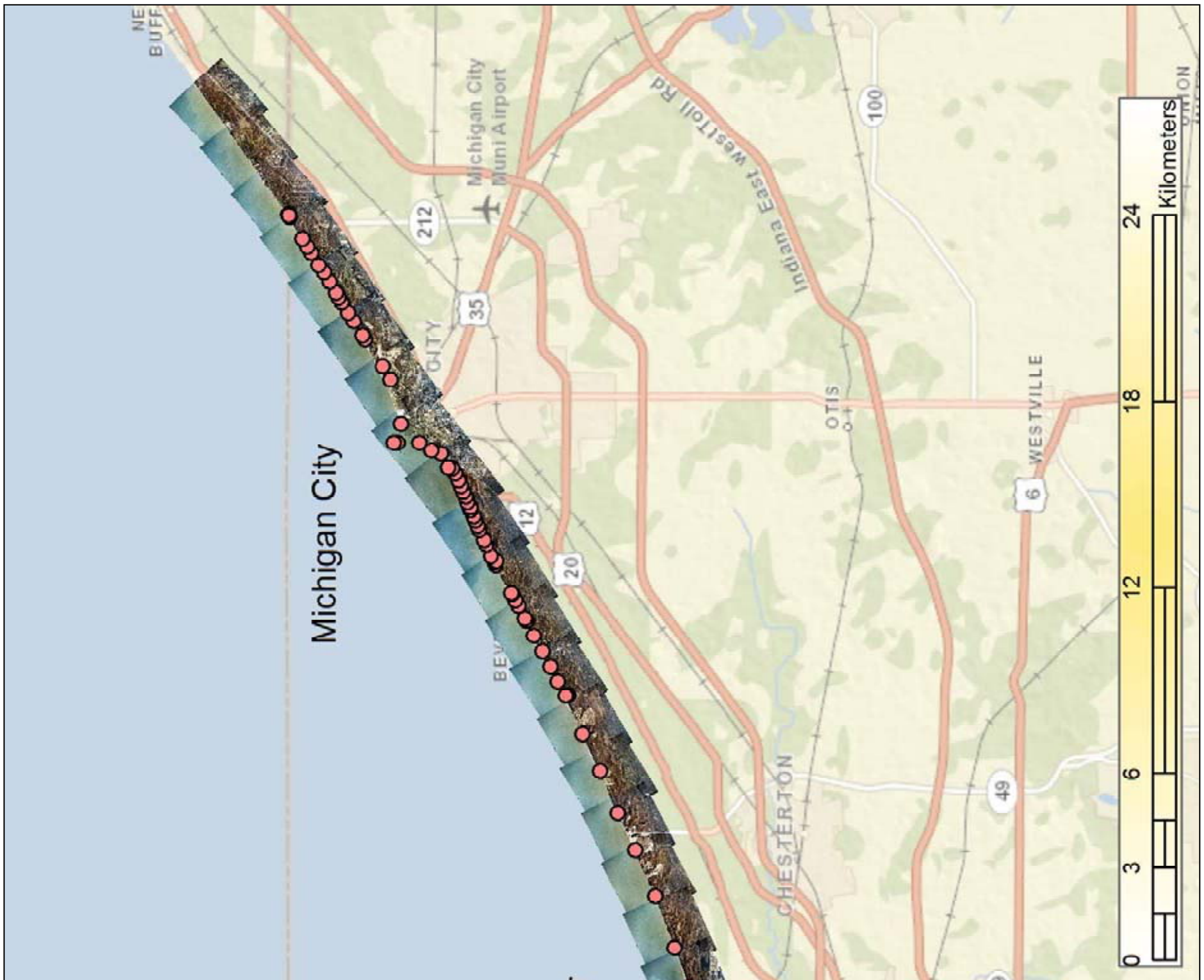

Figure 6. December 2, 1973 aerial photography coverage.

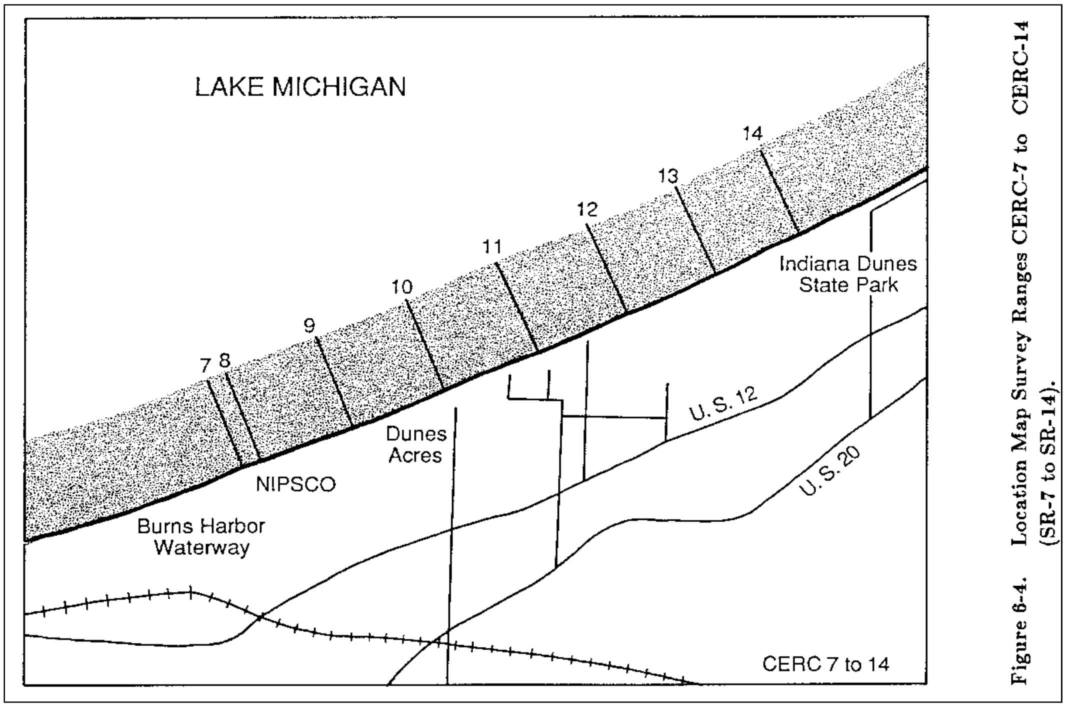

Figure 7. CERC survey lines east of Burns Waterway Harbor (from Wood and Davis 1986).

markers or latitude and longitude coordinates. Some of the survey station locations, specifically in the sand dunes areas, were only identified in the CERC field notes by distance from one station to the next, and did not provide exact on- and offshore location. In the 1986 report, Wood and Davis adjusted the on/off shore survey station locations using aerial photo comparison to fit the CERC surveys to correspond to the newer Purdue surveys. To determine true geographic locations, Mr. Stephen Davis at Indiana Department of Natural Resources (DNR) used the text descriptions on the 1960s survey notes to visually identify the origins using high-resolution photography in Google Earth Pro. Mr. Davis, one of the authors of the 1986 shoreline situation report (Wood and Davis 1986), sent a .kmz file to CHL. This file was converted to a shapefile and plotted in ArcMap. Table 3 lists coordinates in geographic (latitude and longitude) and State Plane units.

The Great Lakes Coastal Research Lab (GLCRL) at Purdue University monitored performance of beach nourishment placed in 1974 and 1981 at Mt. Baldy under contract to the USACE. These profile lines were labeled as "SR" lines and overlap with some of the CERC lines. For example, SR1 was the same as CERC15_A, SR2 was the same as CERC15_B, etc. (Figures 9 and 10; see Table 3 for the complete list). Appendix A reproduces survey notes for profiles SR1-SR18 in the Mt. Baldy region west of Michigan City Harbor provided by LRC to Purdue University GLCRL. Profiles labeled "WBR" from 1984 and 1985 were not used in this study

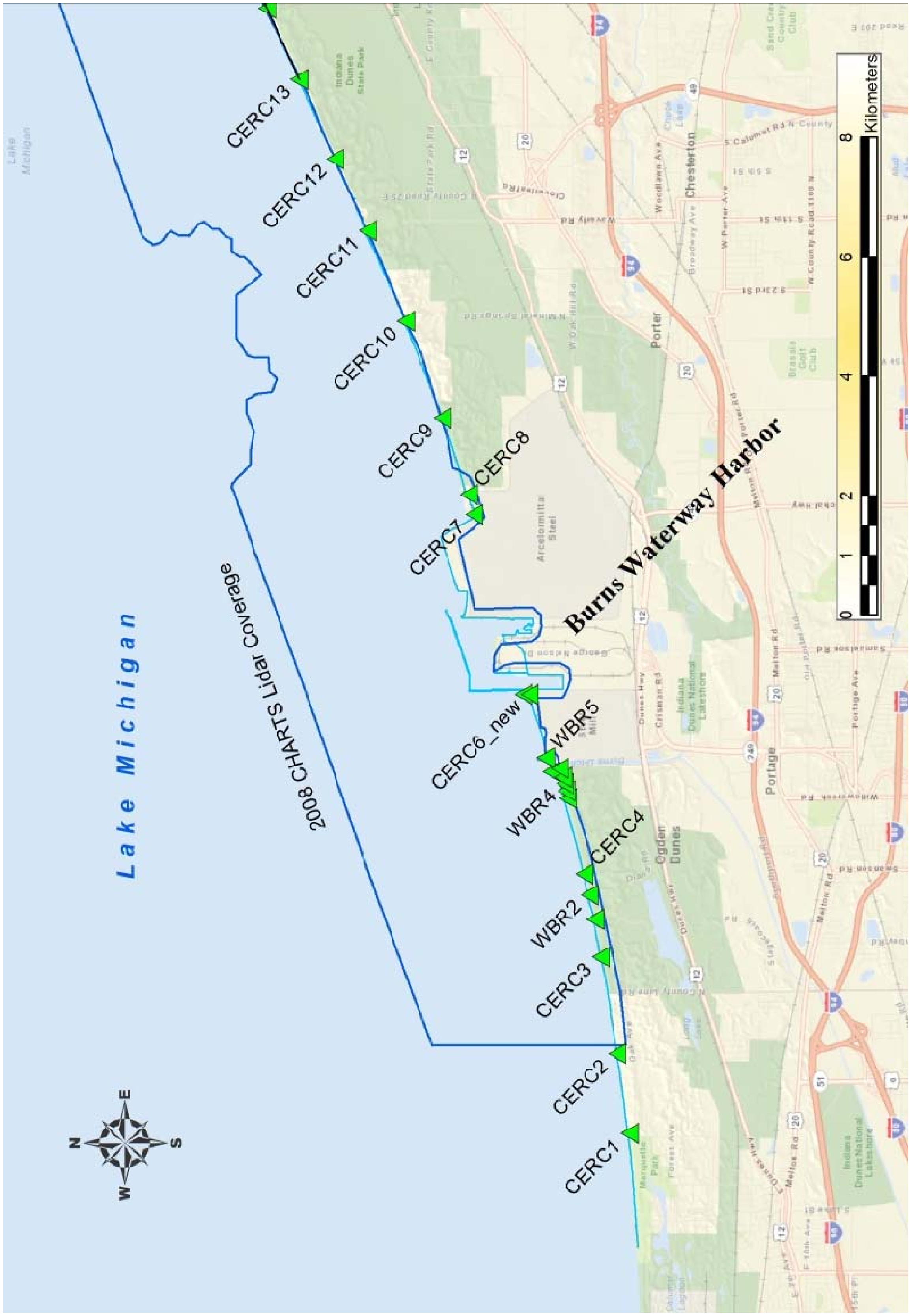

Figure 8. CERC profile monuments near Burns Waterway Harbor. Polygon offshore shows coverage of 2008 Lidar survey (discussed in text). WBR profiles were not used in this study.

Table 3. Cross-shore profile monuments, CERC and SR Lines, 1966-1985.

ID	X_NAD83	Y_NAD83	NORTH_IN_State Plane_NAD27	EAST_IN_State Plane_NAD27
CERC1	41.620801	-87.250881	1501004.44	454188.15
CERC2	41.622712	-87.234890	1501692.66	458561.73
CERC3	41.625177	-87.215443	1502582.10	463880.26
WBR1	41.626042	-87.207811	1502894.17	465967.36
WBR2	41.626894	-87.202917	1503202.73	467305.83
CERC4	41.627688	-87.198710	1503490.47	468456.41
WBR3	41.630173	-87.183467	1504390.73	472624.85
WBR3_5	41.630425	-87.182021	1504482.09	473020.27
WBR4	41.630675	-87.180575	1504572.74	473415.68
700'-1712_68	41.632752	-87.178221	1505328.82	474060.06
S_End_W_Brkwtr	41.630998	-87.179338	1504690.05	473753.99
CERC5	41.631484	-87.177493	1504866.58	474258.58
WBR5	41.633610	-87.175383	1505640.61	474836.24
CERC6_orig	41.636950	-87.162628	1506854.15	478324.21
CERC6_new	41.635977	-87.162597	1506499.61	478332.36
CERC7	41.644489	-87.126450	1509594.14	488215.11
CERC8	41.645301	-87.122464	1509889.49	489304.72
CERC9	41.649315	-87.107072	1511350.55	493512.10
CERC10	41.654828	-87.087526	1513358.47	498854.22
CERC11	41.660622	-87.069373	1515469.94	503814.76
CERC12	41.665641	-87.054973	1517299.70	507749.07
CERC13	41.671036	-87.038923	1519267.35	512133.50
CERC14	41.675946	-87.024592	1521058.77	516047.70
Ref_Pipe	41.680103	-87.009183	1522576.72	520256.02
CERC15_1	41.680885	-87.009685	1522861.55	520118.65
CERC15_2	41.683026	-87.004035	1523643.05	521661.35
SR1_CERC15_A	41.685208	-86.998249	1524439.62	523241.08
SR2_CERC15_B	41.687481	-86.992514	1525269.44	524806.74
CERC16_1	41.689868	-86.986476	1526141.01	526455.01
SR3_CERC16_A	41.692122	-86.980653	1526964.15	528044.49
160+00	41.692479	-86.979780	1527094.52	528282.77
CERC16_B	41.694322	-86.974883	1527767.71	529619.41

ID	X_NAD83	Y_NAD83	NORTH_IN_State Plane_NAD27	EAST_IN_State Plane_NAD27
CERC16_C	41.695152	-86.972698	1528070.90	530215.77
SR4_CERC17_1	41.696236	-86.970383	1528466.71	530847.51
190+00	41.696330	-86.970078	1528501.07	530930.76
SR5_CERC17_B	41.700885	-86.959012	1530164.97	533950.56
PIA	41.701389	-86.957873	1530349.07	534261.34
TRAV_PT1	41.700727	-86.957388	1530108.04	534394.14
SR6_CERC18_1	41.702204	-86.955510	1530646.98	534906.20
CERC18_2	41.703670	-86.951299	1531182.89	536055.33
PIB	41.703626	-86.951234	1531166.89	536073.10
SR7_CERC18_A	41.704254	-86.949639	1531396.39	536508.30
265+29.52	41.705665	-86.945499	1531912.31	537638.00
SR8_CERC18_B	41.706149	-86.943939	1532089.35	538063.70
SR9_CERC18_C	41.706827	-86.941934	1532337.29	538610.79
SR10_CERC18_D	41.707410	-86.940212	1532550.50	539080.65
SR11_CERC19_1	41.708162	-86.937989	1532825.53	539687.20
SR12_0+00	41.708459	-86.936569	1532934.40	540074.76
PID_Near0+00	41.708327	-86.936545	1532886.32	540081.39
SR13_6+00	41.709104	-86.934548	1533170.37	540626.20
SR14_12+00	41.709712	-86.932506	1533392.89	541183.38
SR15_18+00	41.710266	-86.930438	1533595.75	541747.69
SR16_24+00	41.710936	-86.928431	1533840.86	542295.26
SR17_30+00	41.711606	-86.926424	1534085.98	542842.81
SR18_CERC_R2	41.712488	-86.923472	1534408.85	543648.24
SR19_CERC_R1	41.713504	-86.921742	1534779.94	544119.90
PIC	41.714658	-86.921370	1535200.62	544220.67
SR20_CERC20_A	41.716592	-86.916027	1535908.11	545678.10
367+78.65	41.719389	-86.914685	1536927.99	546042.50
SR21_CERC20_B	41.722928	-86.911562	1538219.21	546892.53
Lighthouse	41.729000	-86.911606	1540431.69	546876.11
Lighthouse_ErrorIN_ Notes	41.730208	-86.911619	1540871.86	546871.68
CZM_R21	41.728125	-86.904383	1540116.88	548848.42
CZM_R22	41.730961	-86.887147	1541160.51	553551.01
Turner3456toR23	41.733251	-86.882013	1541998.17	554950.44

ID	X_NAD83	Y_NAD83	NORTH_IN_State Plane_NAD27	EAST_IN_State Plane_NAD27
CZM_R23	41.738553	-86.871483	1543937.01	557819.85
Stop#16	41.739206	-86.870039	1544175.92	558213.37
1910LSD_Google	41.741828	-86.864627	1545135.03	559688.01
2054LSD_Google	41.743386	-86.861378	1545705.00	560573.24
2224LSD_Google	41.745297	-86.857266	1546404.25	561693.61
CZM_R24	41.746044	-86.855414	1546677.78	562198.30
2411LSD_Google	41.746839	-86.853461	1546968.88	562730.49
2608LSD_Google	41.748704	-86.849392	1547651.44	563839.04
2819LSD_Google	41.750283	-86.845664	1548229.58	564854.77
CZM_R25	41.753886	-86.837894	1549548.40	566971.29
STOP32_Menaquet_Trail	41.754944	-86.835460	1549935.82	567634.33
3333LSD_Google	41.756323	-86.832528	1550440.62	568432.88
CZM_R26	41.760023	-86.824117	1551795.63	570723.79
2926LSD_Google	41.751720	-86.842746	1548755.41	565649.57
BrassPlate_DNR_BM_Lap50	41.760356	-86.823108	1551917.80	570998.71
Lake_Shore_Drive	41.760398	-86.823191	1551933.03	570976.02
MichianaDrive	41.760252	-86.823113	1551879.90	570997.46
Shadow_Trail	41.760191	-86.822900	1551857.84	571055.64
MI_IN_StateLinePlate	41.760275	-86.823539	1551887.93	570881.21

Notes:

Geographic coordinates (latitude and longitude) are NAD83 in decimal degrees.

State Plane coordinates Indiana WEST; NAD27; Zone 1302; US Survey Feet.

Coordinate data provided by Indiana Department of Natural Resources (Mr. Steven Davis) based on original survey field books and other documentation.

Starting in 1996, the USACE began a regular beach fill nourishment program at Mt. Baldy. From 1996 to 2004, another series of profiles were collected to monitor the beaches before and after the fills at Mt. Baldy. The survey work was conducted by American Surveying Consultants, P.C., and Plumb Tuckett & Associates. These surveys did not coincide with the older CERC and SR lines but in many cases were close (Figure 11). Table 4 lists the monumentation for 1996-2004 surveys.

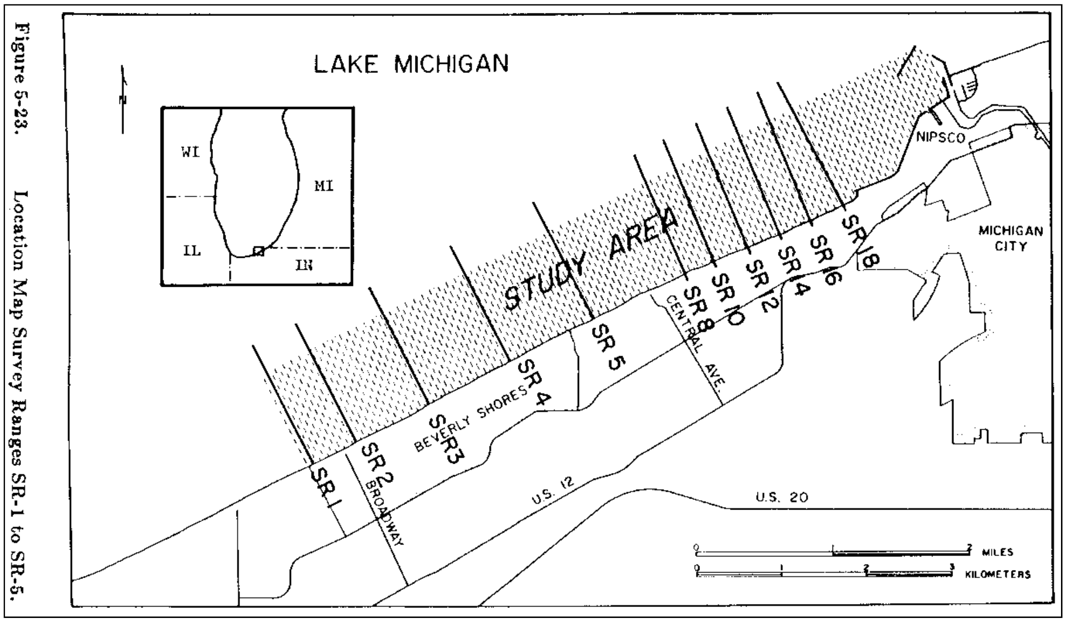

Figure 9. SR survey lines west of Michigan City Harbor (from Wood and Davis 1986).

4.4.2 Recovery of 1960s and 1970s profile data

The GLCRL processed and examined the CERC and SR profiles and other coastal process data in the mid-1980s and prepared a shoreline situation report (Wood and Davis 1986). The profiles were plotted with an electronic pen plotter, but the digital files were lost over the years. Attempts to recover files from the GLCRL, University of Michigan, and the author's son were unsuccessful. To recover the data, Indiana Department of Natural Resources sent high-quality scans of the plots in the report to CHL (Stephen Davis, Indiana Department of Natural Resources, 15 June 2011, personal communication). A technician at CHL digitized the TIFF files onscreen using Didger® V. 4.0 software, saving the data as distance-elevation pairs in ASCII text files. On these plots, distances were referenced to the origin position for each profile, and elevations were referenced to low water datum based on the IGLD1955 (National Oceanic and Atmospheric Administration 1980; Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data 1992). The profiles were imported into RMAP software for analysis and volume calculations. Figure 12 shows the CERC8 plots from Wood and Davis (1986), and Figure 13 shows the same profiles after digitizing and importing into the RMAP.

Note the confusing nomenclature on the plot labels. CERC8 was also labeled as SR-8. This is NOT the same SR-8 as the SR profiles further east (see Table 3). In this report, these 1960s and 1970s profiles are referred by their CERC labels, not by the confusing SR labels.

Figure 10. CERC and SR profile locations, east region near Michigan City Harbor. Profiles east of Michigan City were not analyzed for this study. Polygon offshore shows coverage of 2008 Lidar survey.

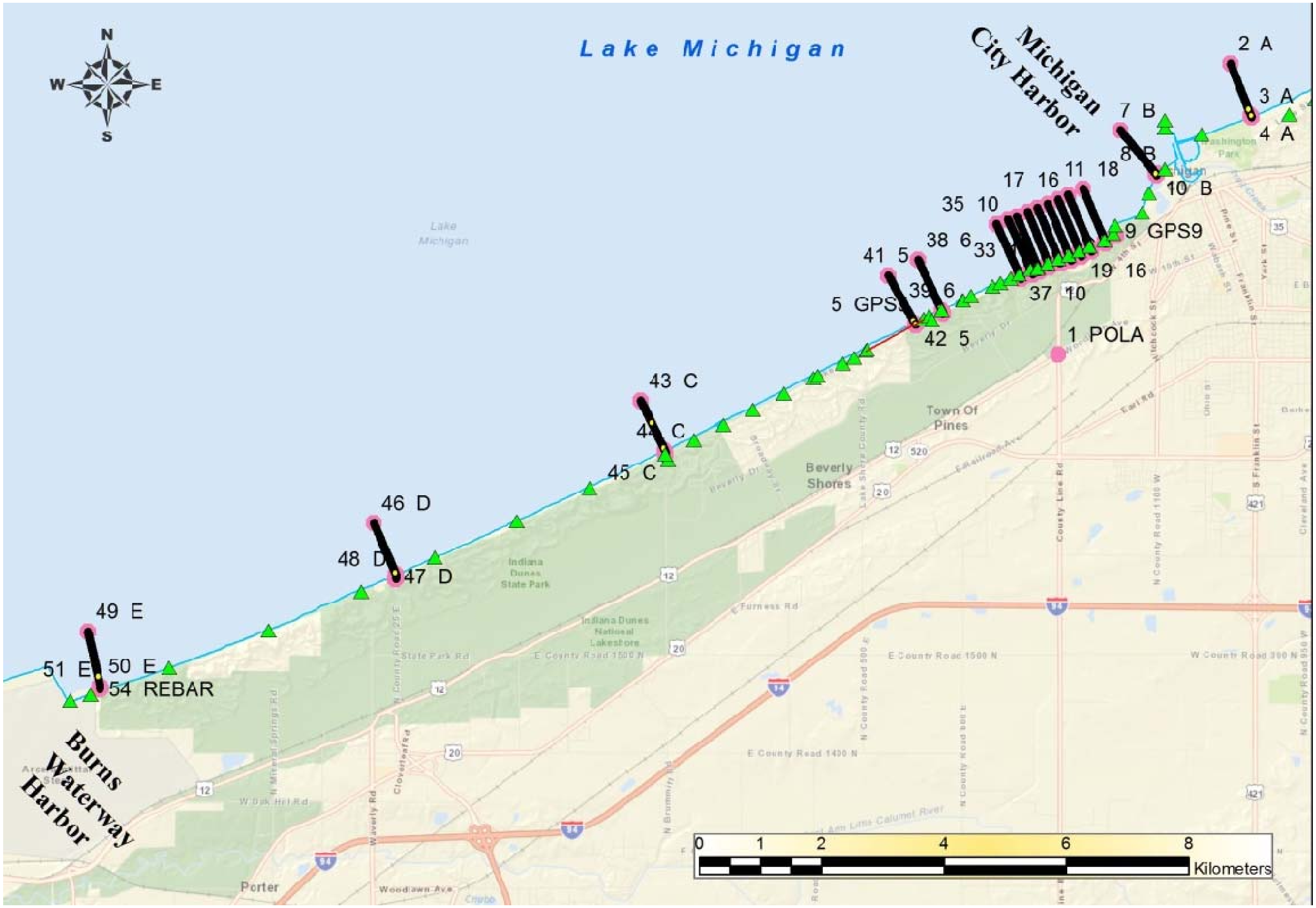

Figure 11. Profiles from 1996-2004 monitoring program (black lines). Green triangles are CERC and SR monuments (not labeled).

Table 4. Cross-shore profile monuments, 1996-2001 lines.

ID	Northing	Easting	ELEV (IGLD85)	ELEV (LWD)	Profile
1	2348533.760	2993910.191	618.93	41.09	POLA
2	2364184.063	3003130.632	-99999	-99999	A
3	2361389.585	3004221.912	-99999	-99999	A
4	2361293.842	3004259.301	593.88	16.04	A
5	2350154.740	2986241.431	593.51	15.67	GPS5
6	2353513.150	2994145.521	598.41	20.57	GPS6
7	2360583.893	2997236.506	-99999	-99999	B
8	2358256.098	2999128.957	-99999	-99999	B
9	2354935.700	2997021.341	633.02	55.18	GPS9
10	2358179.014	2999180.987	584.65	6.81	B
11	2357430.003	2995237.629	-99999	-99999	18
12	2354659.630	2996388.731	-99999	-99999	18
13	2354506.050	2996452.544	615.44	37.60	18
14	2357107.133	2994432.049	-99999	-99999	17
15	2354336.760	2995583.151	-99999	-99999	17
16	2354085.669	2995687.480	606.03	28.19	17
17	2356865.128	2993892.080	-99999	-99999	16
18	2354091.652	2995035.683	-99999	-99999	16
19	2353806.897	2995153.097	618.30	40.46	16
20	2356619.967	2993344.580	-99999	-99999	15
21	2353846.511	2994488.233	-99999	-99999	15
22	2353588.185	2994594.755	605.62	27.78	15
23	2356416.697	2992779.426	-99999	-99999	14
24	2353643.530	2993923.780	-99999	-99999	14
25	2353430.120	2994011.844	612.19	34.35	14
26	2356207.700	2992254.995	-99999	-99999	13
27	2353421.261	2993366.639	-99999	-99999	13
28	2353233.614	2993441.502	609.59	31.75	13
29	2355958.391	2991671.502	-99999	-99999	12
30	2353184.991	2992815.291	-99999	-99999	12
31	2352999.462	2992891.806	615.56	37.72	12
32	2355808.369	2991188.168	-99999	-99999	11
33	2353076.380	2992427.618	-99999	-99999	11
34	2352847.060	2992531.656	611.14	33.30	11
35	2355533.333	2990581.800	-99999	-99999	10

36	2352801.240	2991821.021	-99999	-99999	10
37	2352599.726	2991912.423	615.92	38.08	10
38	2353616.201	2986378.221	-99999	-99999	6
39	2350897.480	2987646.511	-99999	-99999	6
40	2350751.768	2987714.486	617.64	39.80	6
41	2352774.602	2984779.814	-99999	-99999	5
42	2350087.497	2986278.945	622.74	44.90	5
43	2346021.847	2971520.145	-99999	-99999	C
44	2343319.628	2972823.224	-99999	-99999	C
45	2343188.570	2972848.588	595.89	18.05	C
46	2339427.338	2957201.517	-99999	-99999	D
47	2336673.233	2958391.014	-99999	-99999	D
48	2336423.444	2958391.014	587.23	9.39	D
49	2333581.683	2941884.677	-99999	-99999	E
50	2330653.517	2942537.245	-99999	-99999	E
51	2330475.612	2942537.245	589.06	11.22	E
52	2343136.876	2972858.602	-99999	-99999	REBAR
53	2336412.436	2958371.436	-99999	-99999	PK_NAIL
54	2330501.278	2942588.800	-99999	-99999	REBAR

Notes:
From text file CONTROL.ASC from 2001 Plumb Tuckett & Associates.
Northing and Easting values are State Plane coordinates Indiana WEST; NAD83; Zone 1302; US Survey Feet.

4.4.3 1996-1998 profile data

For the 1996-1998 profiles, the digital data consisted of AutoCAD® .dwg files supplied by USACE Buffalo District. Profile distance and elevation were extracted by GIS technicians at LRC.

As stated earlier, 1996-2004 profiles were collected at different locations along the shore than the older CERC lines. To compare these newer profiles with the nearest CERC lines, they had to be adjusted shoreline perpendicular. For example, the zero monument for the 2001 “E” profile, Point 50E, was located lakeward of the zero position of the closest CERC line, in this case CERC8 (Figure 14). The adjustment procedure was as follows:

1. Draw a straight baseline connecting CERC8 and CERC9.
2. Measure the distance from 50E to the baseline = 326.6 ft.

3. Using Excel spreadsheet, compute offshore distance from X-Y points using the relation: Dist = SQRT ($X^2 + Y^2$)
4. Move all points on Line E laterally: $Dist_{Adjust}$ = Dist + 326.6 ft
5. Adjust for IGLD datum: $Elev_{IGLD1955} = Elev_{IGLD1985} - 0.7$ ft
6. Import distance-elevation data into RMAP software and directly compare with older CERC8 profiles.

Adjustment distance for:

1. D profiles to match CERC12: 90.2 ft.
2. C profiles to match CERC15_1: 201.5 ft.
3. Line 5 (GPS5) profiles to match CERC17_B (SR05): -12.9 ft.

4.4.4 2001, 2003, and 2004 profile data

These data were available as ASCII files and could be imported directly into Excel spreadsheets. These profiles were adjusted laterally by the same procedure outlined above. If the elevations were listed as total elevation IGLD1985, the value was adjusted to compare with LWD:

$$Elev_{IGLD1955} = Total\_Elev_{IGLD1985} - 577.5 - 0.7 \text{ ft}$$

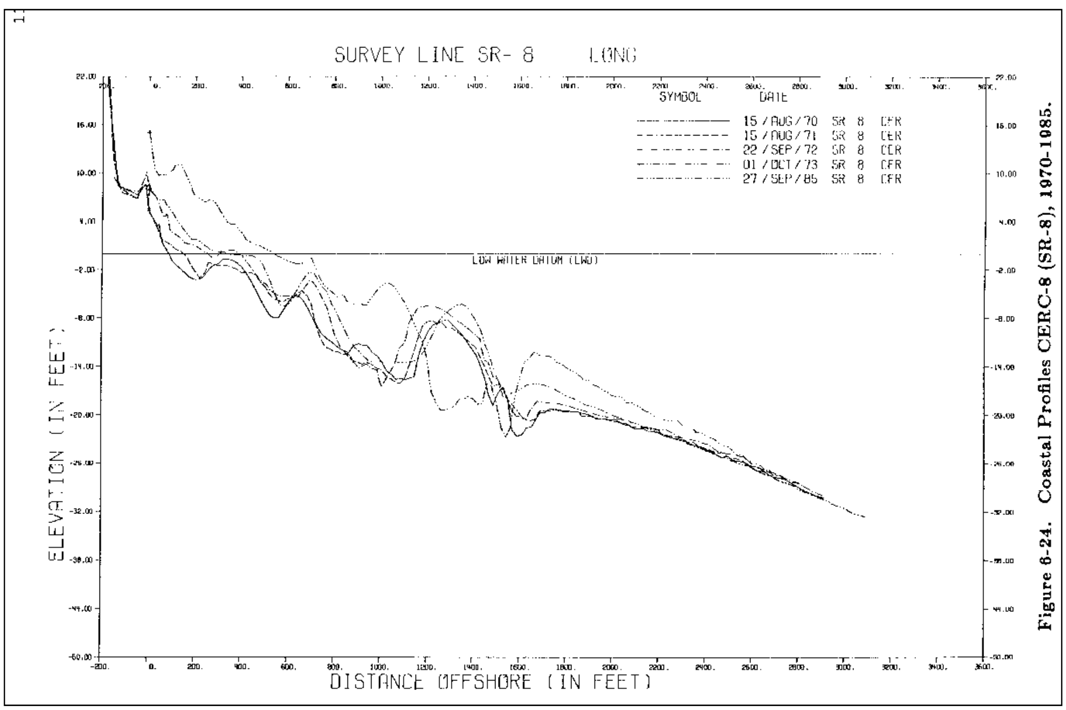

Figure 12. Example of cross-shore profiles from CERC8 as plotted in Wood and Davis (1986), p. 118. Note confusing use of dual labels, CERC8 and SR-8. This is different than the SR8 profile location further east near Mt. Baldy.

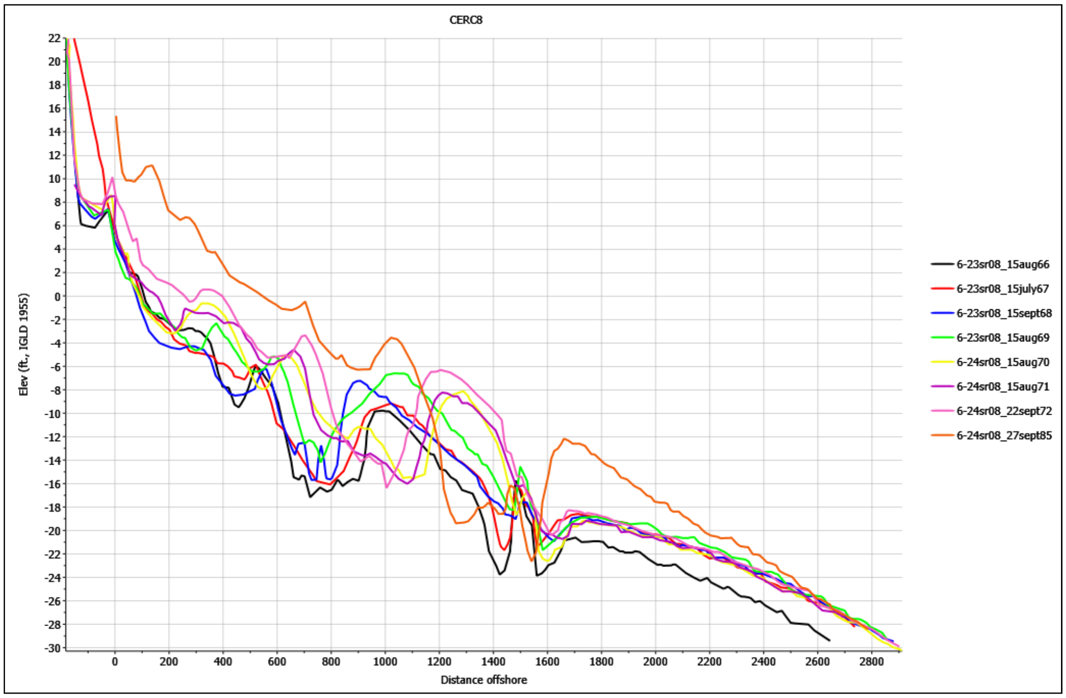

Figure 13. CERC8 profiles redrawn and imported into RMAP software. Original English units (ft) and elevations with respect to LWD IGLD1955 have been retained.

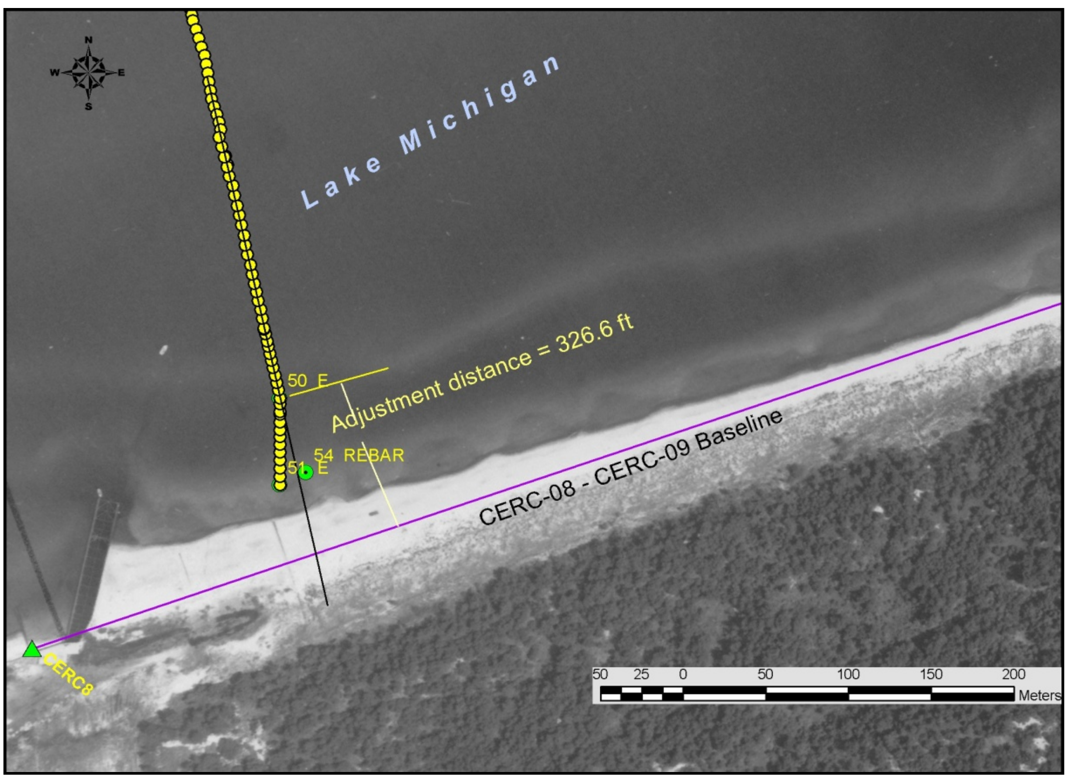

Figure 14. Adjustment of 2001 Line E profiles to match baseline between CERC8 and CERC9. Monument 50E, the zero point for the 2001 profile, is 326.6 ft lakeward of the baseline. A similar procedure was used for other profile locations.

5 2008 Lidar data

No cross-shore profiles have been collected in the study area after 2004. To determine recent bathymetry, profiles were cut from 2008 Lidar data. This Lidar data was collected under the USACE National Coastal Mapping Program (NCMP) by the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system along the coast of Illinois and Indiana over a period from September 17, 2008, through September 26, 2008 (Macon 2009; Wozencraft and Millar 2005; Wozencraft and Lillycrop 2006). Coverage typically extended from the waterline 1600 ft (500 m) inland and offshore 3,300 ft (1,000 m) or to laser extinction (Figures 8 and 10). The post-processed data was provided with an x-spacing of 25 ft, y-spacing of 35 ft, and horizontal and vertical datum of NAD83 and NAVD88, respectively.

The Lidar data was converted to a triangulated irregular network (TIN) using ArcGIS v. 9.3. Profile cut lines were generated as features originating from the CERC benchmarks and extending perpendicular to the shore offshore to the limit of the Lidar data. The elevation data along these cut lines was extracted using the 'Create Profile Graph' function of the 3D Analyst extension and exported to an ASCII file. The data was then converted to units of feet and to IGLD1985 vertical datum. To compare with the historical profiles, elevations were adjusted to IGLD55.

The 2008 profiles matched the earlier traditional surveys closely at CERC7, CERC8, and CERC15-1. But at other locations, the Lidar lines were unrealistically low. Experiments with changing the gridding and tinning procedures could not resolve these discrepancies and the Lidar cut lines could not be used at the other profiles.

2012 acoustic bathymetry data

On April 18, 2012, a bathymetry survey was run east of the federal harbor offshore of CERC7 and CERC8. The data was collected with an acoustic echosounder and supplied to CHL in the form of 10-ft gridded data points in an ASCII xyz data file. These data were converted to a shapefile, then converted to a triangulated irregular network (TIN) using ArcGIS v. 10 (Figure 15). Profiles were cut along the same azimuths as the historical lines at CERC7 and profile E. The elevation data along these cut lines was extracted using the 'Create Profile Graph' function of 3D Analyst and

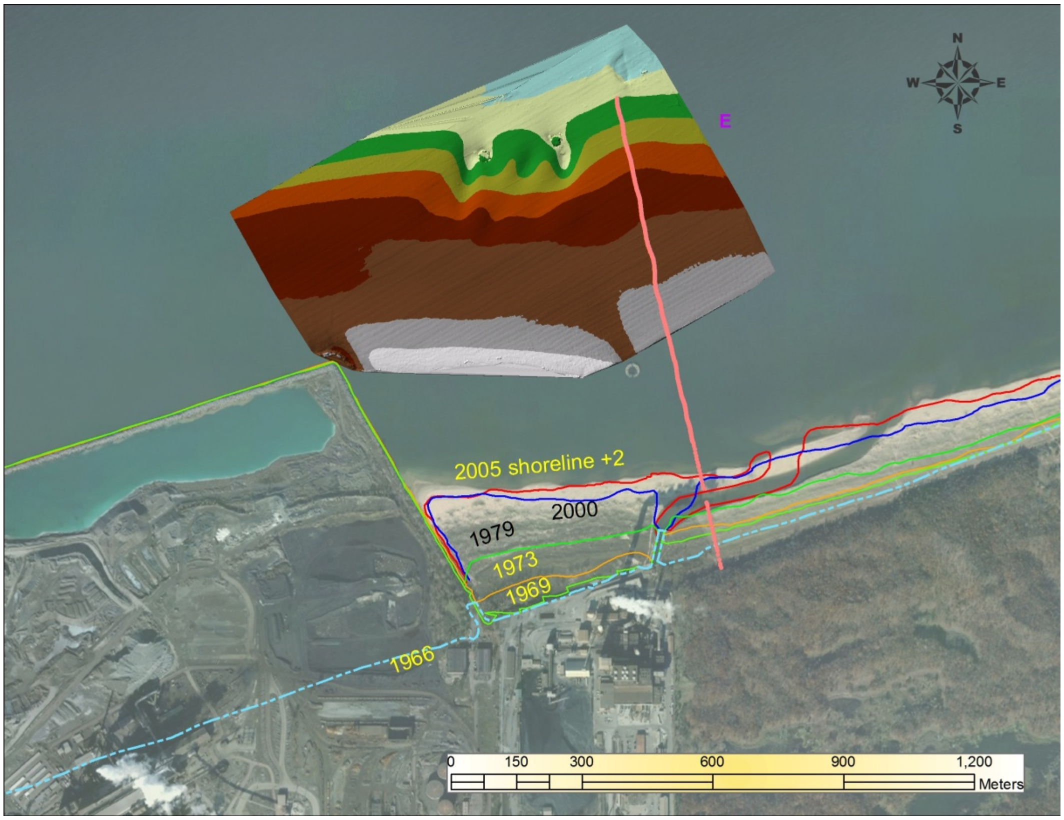

Figure 15. April 18, 2012 survey coverage. Data has been processed with a triangulated irregular network (TIN). New data partially overlaps survey line E (2004 pre-placement survey shown). Background photograph approx. October 2011 (specific date not listed, from ESRI Maps and Data).

exported to an ASCII file. The distance data was then converted to units of feet. To compare with the historical profiles, elevations were adjusted to IGLD1955:

$$\mathrm{Elev}_{\mathrm{IGLD1955}} = \left(\mathrm{Total\_Elev}_{\mathrm{IGLD1985}}\right) - 577.5 - 0.7\ \mathrm{ft}$$

Because of weather constraints, the 2012 data did not extend across the fillet to the beach. When plotted in comparison with the older profiles, CERC7 shows some of the offshore region to be about 4-5 ft higher than in 2008, and at CERC8-Line e, about 2-3 ft higher (see plots in Appendix C). To compare with older profiles, the 2012 cut profiles had to be extended to the beach (zero position) with a straight line. The straight line was run to approximately match the slope of the 1985 profile. In shallow-water, the 2012 surface may be higher than 1985 as the fillet has filled. Therefore, the volume calculation for 2012 is conservative and the true volume may be higher.

6 Shoreline Mapping

6.1 Photograph transformation

Transforming raster photographs consisted of importing each raster image into the ArcMap project, crudely fitting it into the approximate correct position, and then refining the fit by identifying common points between the historical and the contemporary photographs. The most useful reference points were:

1. Corners of prominent buildings such as schools, factories, and some houses;
2. Sidewalks, walkways, or road intersections;
3. Industrial chimneys or other prominent objects;
4. Some in-water features like breakwater stones or the BGS water intake.

In some areas, the centerlines of roads could be used as match points. But, roads are not necessarily trustworthy indicators because many have been widened during the 20th century, and it is often unclear if a road was uniformly widened on both sides or if the highway department added lanes on one side or the other. Similar uncertainty exists with railroad tracks when extra rail lines were added to a right-of-way.

Most photographs were fit with 1st order or 2nd order polynomial transformation. As per the ArcMap™ help file, "The polynomial transformation uses a polynomial built on control points and a least squares fitting (LSF) algorithm. It is optimized for global accuracy but does not guarantee local accuracy." Most of the 1960s and 1970s photographs could not be matched with a sufficient number of reference points to allow spline transformation, which usually allows more precise fitting in the region of the match points. Some of the photographs spanning the Indiana Dunes National Lakeshore were challenging to georeference because of the few man-made features in the woods and marshes.

6.2 Shoreline changes

Shorelines were drawn visually from the georeferenced aerial photography. Based on a procedure used in the shoreline analysis report prepared by Buffalo District, the shorelines were adjusted to +2.0 ft LWD, IGLD 1985

(USACE Buffalo 2008). Table 5 lists the lateral correction based on an average beach slope of 1:10. This was the typical beach slope near the waterline on prenourishment surveys obtained in 2004 at profiles SR10, SR12, SR14, SR16 and SR18.

Table 5. Correction to aerial photograph shoreline to +2 ft LWD (based on average beach slope of 1V:10H)[1].

Date	Water elev. (m, IGLD85)[2]	Water elev. (ft, IGLD85)[3]	Water level (ft, LWD)	Shoreline correction distance to LWD[4]	Shoreline correction distance to +2 ft LWD[5]
4-Nov-1966 *	176.01	577.46	-0.04	0 ft landward	20 ft landward
15-Apr-1967	176.23	578.18	0.68	7 ft lakeward	13 ft landward
4-Dec-1967	176.32	578.48	0.98	10 ft lakeward	10 ft landward
5-Jun-1968	176.47	578.97	1.47	15 ft lakeward	5 ft landward
28-Jun-1969 *	176.82	580.12	2.62	26 ft lakeward	6 ft lakeward
7-Apr-1971	176.76	579.92	2.42	24 ft lakeward	4 ft lakeward
2-Dec-1973 *	177.00	580.71	3.21	32 ft lakeward	12 ft lakeward

Notes:

1 Typical beach slope near the waterline based on 2004 prenourishment surveys at profiles SR10, SR12, SR14, SR16 and SR18 (USACE Buffalo 2008).

2 Water elevation based on monthly mean historical water level data from The Canadian Hydrographic Service (http://www.waterlevels.gc.ca/C&A/network_means.html). Levels are based on a coordinated network of gauging stations for each of the Great Lakes.

3. Low Water Datum (LWD) for Lake Michigan = 577.5 feet IGLD85.

4. Methodology for shoreline correction obtained from report "Indiana Shoreline Monitoring: Burns International Harbor to Michigan City Harbor 2008" (USACE Buffalo, 2008).

5. Analysis of shoreline correction distance by Mr. Paul Szempruch, US Army Engineer District, Galveston.

* Dates used in this study.

6.3 Historical changes

Construction of Burns Waterway Harbor began during late-1966. Figure 16 (November 4, 1966) shows the beach with a short section of the Arcelor-Mittal (at that time, Bethlehem Steel) bulkhead projecting into the lake. The shoreline was approximately straight with sand accumulation to the east (right) of the BGS power plant outfall canal (near CERC8 monument). West of the BGS plant, beyond CERC7, the shoreline was slightly indented, indicating retreat.

By April of 1967, the bulkhead was longer, but the shoreline configuration remained almost unchanged (Figure 17). By December, the bulkhead extended out into the lake, but the shoreline showed little change (Figure 18). Note how the dunes in the factory site had been mined for sand.

Figure 16. Shoreline at initial stage of Burns Waterway Harbor construction, November 4, 1966. Bulkhead was under construction near CERC7.

Figure 17. April 15, 1967 photograph (non-georeferenced) showing increased length of bulkhead.

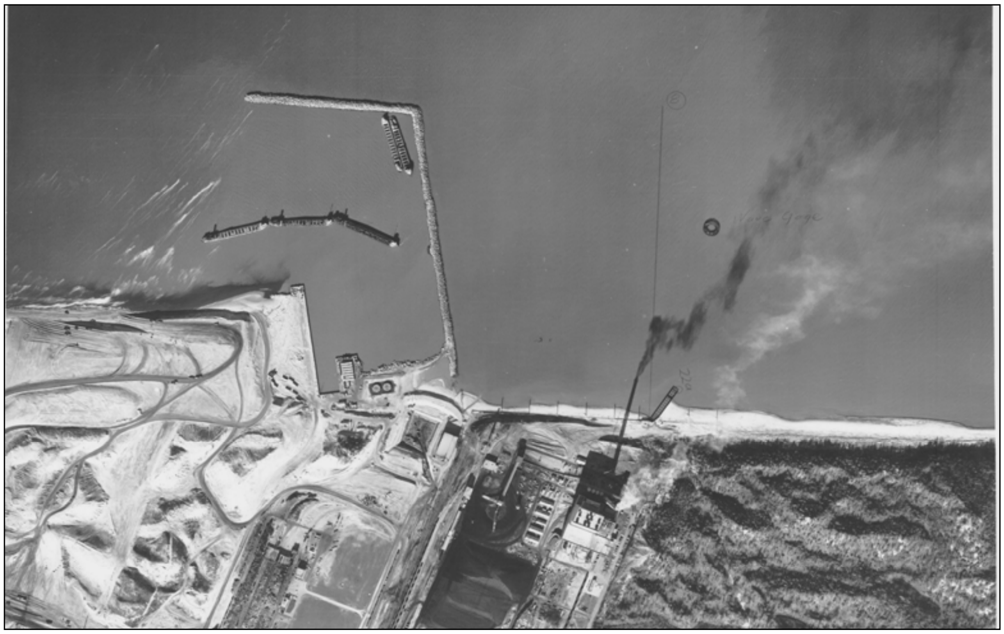

Figure 18. December 4, 1967. Bethlehem Steel (now Arcelor-Mittal) bulkhead construction is well along and the former dunes in the construction area have been mostly flattened. Shoreline configuration east of the bulkhead shows minimal change.

By June 28, 1969, the bulkhead had been completed, and the former open lake nearshore was being filled with sand (Figure 19). The enclosed area was also intended to serve as Bethlehem Steel's permitted lakefill disposal site for slag. Along the shoreline, additional sand had been trapped east of the NIPSCO BGS outfall canal, and the shore had retreated between the cross-shore groins near CERC7. The area west of the bulkhead became a storage area for coal, a use that remains to this day. As an example of the extent of industrial development, Figure 20 shows Burns Waterway Harbor under construction with the 1966 shoreline superimposed.

The April 1971 aerial photograph shows that some sediment had accumulated between and around the groins, but no accumulation was yet evident against the bulkhead (Figure 21). If the bulkhead was porous, some sand would have passed through into the lagoon, which was slowly being filled as part of the harbor project. Note that five ore carrier ships were sunk within the bulkhead, to become part of the fill.

By December 1973, the groins were under sand, and the beach east of the BGS outfall canal is noticeably wider than in previous years (Figure 22). Sediment was also accumulating offshore. In 1978, Sargent and Lundy (1978) reported that the NIPSCO BGS intake crib, originally constructed in 20 ft water depth, was then in only 15 ft of water and sand was being introduced into the circulating cooling water system.

Figure 19. June 28, 1969. The Bethlehem Steel bulkhead was finished and former lake nearshore was being filled with sand. The shoreline shows some additional trapping east of the NIPSCO BGS outfall canal and minor loss between the cross-shore groins near CERC7. White line is border of photographic print.

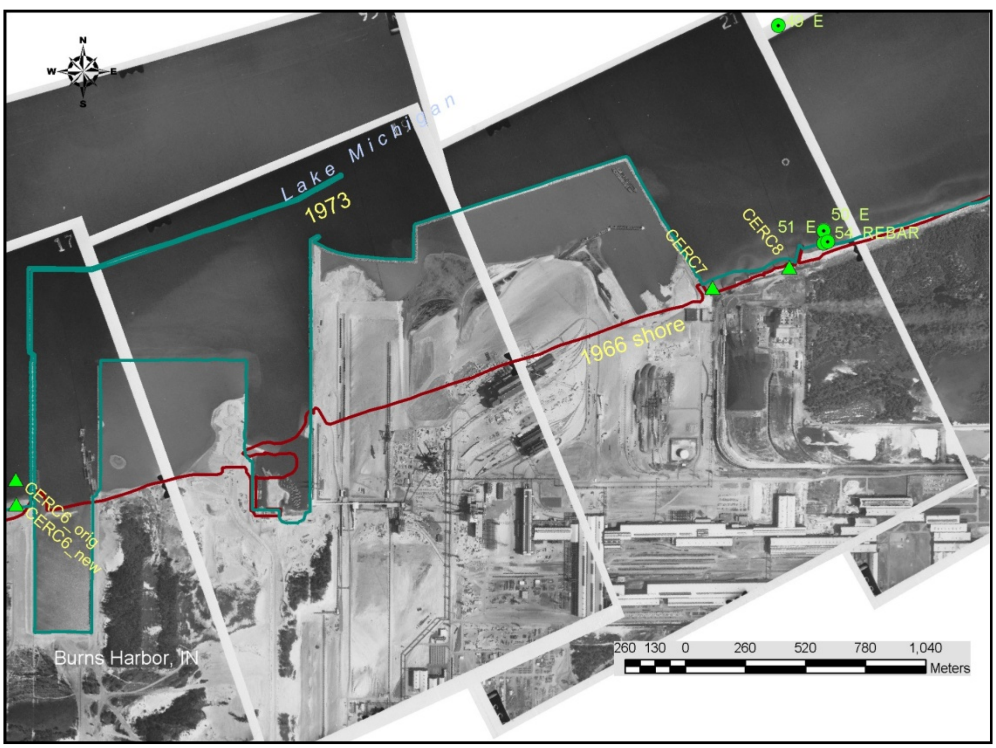

Figure 20. June 28, 1969. Burns Waterway Harbor under construction, with 1966 and 1973 shorelines to show extent of changes.

Figure 21. April 7, 1971. Sand had accumulated in and around the NIPSCO BGS groins compared to 1969.

Figure 22. December 2, 1973. Enough sediment had accumulated to bury the groins, and the beach was wider than in previous years.

As the years passed, sediment accumulated in the fillet east of the Arcelor-Mittal (then Bethlehem Steel) bulkhead to the extent that the BGS intake had to be dredged to prevent sand from clogging and damaging the cooling water piping inside the plant. The 2005 photograph shows the extent of sand accumulation (Figure 23), and the 2011 photograph shows the fillet extending out into the lake about half the length of the bulkhead (Figure 24).

Approximately the western half of the reach between Michigan City Harbor and Burns Waterway Harbor is mildly accretional, according to the analysis conducted by USACE Buffalo (2008). Only the eastern half of the reach in the Mt. Baldy area has the beach retreated over time. Figure 25 shows the 1966 shoreline compared to 2005, but the figure does not show the full natural retreat that actually occurred before 1966, when the USACE began a 50-year beach nourishment project. Sand added to the system created the wide 2005 beach shown in the aerial photo.

Erosion of the shore west of Michigan City Harbor began in 1836, when the first Trail Creek structures were built. Later construction of the seawall at Michigan City NIPSCO generating station caused the highest erosion

Figure 23. March 2005 orthophotograph from Indiana Spatial Data Portal, with shorelines superimposed. All shoreline represent +2 ft LWD IGLD1985. Beach had grown significantly compared with 1979 and earlier.

Figure 24. October 2011 (specific date not listed, from ESRI Maps and Data). The fillet extended to about half the length of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead, but the shoreline had not changed greatly since 2005. All shorelines represent +2 ft LWD IGLD1985.

Figure 25. 1966 and 2005 +2 ft LWD IGLD1985 shorelines in the Mt. Baldy area, showing overall shore retreat. A shoreline (not available) from before the 50-year nourishment program was initiated in 1996, would have shown a much greater retreat. The 1996 pre-nourishment shore position can be approximated by the dark line (or shadow on the dune face) located between the trees still remaining at the top of the eroded dune face – and the lighter colored sand of the wide 2005 beach.

zone to be transferred downdrift to the Crescent Dune/Mt. Baldy area (creating sand-starved conditions). This long term erosion resulted in the loss of all sand bars offshore of Mt. Baldy, exposing clay valleys offshore and clay at the beach. The first beach nourishment project at Mt. Baldy placed quarry-derived sand between SR-12 and SR-17 in 1973-1974. Another project was performed in 1981 when the 1974 fill eroded away. This latter beach nourishment resulted in the return of some nearshore offshore sand bars that were absent before. After the 1981 project, only sand dredged from the Trail Creek federal navigation channel contributed sand to the sand-starved Mt. Baldy shoreline until 1996. In 1996, the erosion at Mt. Baldy had become so severe that clay was again exposed above the water and at the toe of the dune. Another fill using quarry-derived sand was placed at Mt. Baldy, and the USACE began a 50-year program of yearly beach nourishment, resulting in the return of a wide beach in front of Mt. Baldy. The 1996 beach nourishment and continued placement of dredged Trail Creek sand, in combination with long-term below-average lake levels since 1999, has contributed to the wide beaches seen in the 2005 aerial photos (Stephen Davis, Indiana DNR, personal communication, February 24, 2012).

W.F. Baird & Associates (2004; p. 58) calculated that between 1938 and 2002, the Mt. Baldy area suffered about 106,000 yd^3/year volume loss from shoreline and dune erosion. The Baird values were based on shoreline position measured from georeferenced 1938 and 2002 aerial photographs. But, as stated above, the beach nourishments at Mt. Baldy have largely stabilized the shoreface. Therefore, the volume losses computed by Baird applied to the period 1938-1996 and may be higher than current conditions. Placement at Mt. Baldy from 1996-2010 has averaged 45,000 yd^3/year (tabulated later in this report).

7 Sediment Budget Cells

A sediment budget is a tallying of sediment gains and losses, or sources and sinks, within a specified control volume (or cell), or series of connecting cells, over a given time. Cells are defined by geologic features or natural geomorphic boundaries, data resolution, coastal structures, and knowledge of the site. Sediment may pass from one cell to another, either naturally by wave and current-induced transport or artificially via dredging and placement. Rosati (2005) provides a more complete description of sediment budget methodology.

The basic sediment budget equation can be expressed as:

$$\sum Q_{\text{source}} - \sum Q_{\text{sink}} - \Delta V + P - R = \text{ Residual}$$

where:

- Q_{source} and Q_{sink} are the sources and sinks to the control volume, respectively;
- ΔV is the net change in volume within the cell;
- P is the amounts of material placed in the cell;
- R is the amounts of material removed from the cell;
- *Residual* represents the degree to which the cell is balanced.

For a balanced cell, the residual is zero. For a region consisting of many contiguous cells, the budgets for individual cells must algebraically balance in achieving a balanced budget for the entire regional system.

Table 6 summarizes sediment gains and losses that may apply to a Lake Michigan budget cell. Not all of these are applicable today. For example, sand mining is no longer conducted. Wind transport is difficult to evaluate without conducting an Aeolian transport analysis. Figure 26 shows the two sediment budget cells considered for this study.

In this case, beach accretion east of the Arcelor-Mittal bulkhead (ΔV) is entered as a positive value. Sediment from updrift is shown as a flux into the cell. Artificial sediment movement out of the cell, such as the bypassing at Burns Waterway Harbor, is not shown as a flux but rather is entered as a positive number for the term R (for removal). Artificial placement, such as at Mt Baldy, is entered as a positive number for term P.

Table 6. Sediment gains and losses for budget calculation

Gains	Losses
Longshore transport into cell	Longshore transport out of cell
Riverine supply	Offshore transport (to deep water)
Bluff erosion	Wind transport inland or out to lake
Wind transport onto the beach	Transport into dredged navigation channels
Onshore transport	Beach mining or other anthropogenic causes
Beach nourishment	
Dumping of debris	

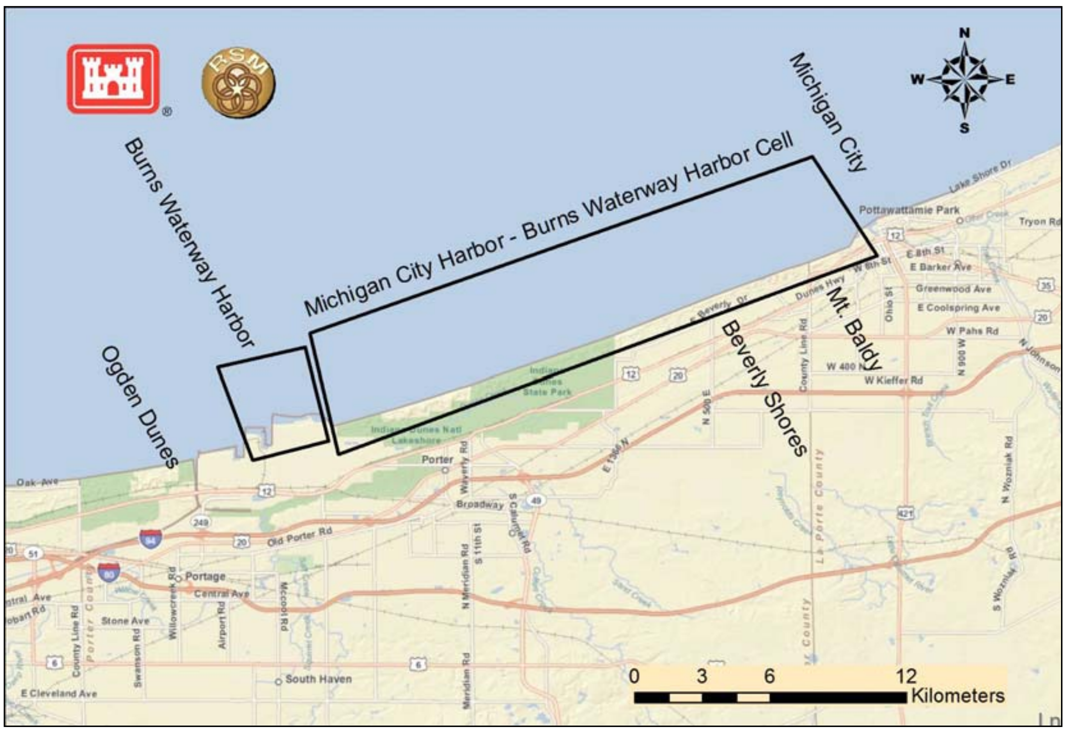

Figure 26. Sediment budget cells for the study area.

Each cell represents a geomorphic unit that includes the beach and the shallow nearshore zone. The dimension alongshore represents the approximate linear extent of the cell, but the shore-perpendicular width does not represent a value or dimension. The depth of the nearshore zone is unspecified but is intended to include the active sediment zone (approximately 25 ft water depth). Cells have been drawn with exaggerated cross-shore dimension for display purposes.

7.1 Sediment placement and removal

Table 7 lists sand placement in the Mt. Baldy area. Annual average placement for the period from 1996, when an annual nourishment program was initiated, through 2010 was 45,000 yd^3/year (674,650 yd^3 ÷ 15 years). Earlier nourishments were not included in the average because of multi-year gaps. Inland source means sand brought to the site by truck from approved quarries.

Table 7. Mt. Baldy nourishment quantities.

Year	Inland source (yd^3)	Mich. City Harbor source (yd^3)	Total placement (yd^3)
1974	227,000		227,000
1981	80,000		80,000
1986		68,000	68,000
1992		74,600	74,600
1996	57,000	48,200	105,200
1997	73,000		73,000
1998	107,000		107,000
1999	36,000		36,000
2000		85,200	85,200
2001	42,750		42,750
2003	52,300 [a]		52,298
2004	17,500 (23,700 tons)		17,500
2005	9,500 (11,400 tons)	14,000	23,500
2006		41,300	41,300
2007	17,300 (19,000 tons)		17,300
2008	17,300 (19,000 tons)		17,300
2010	56,300 (90,000 tons)		56,300
Total vol.			1,124,250
Vol. 1996-2010 [b]	485,950	188,700	674,650
Average annual vol. 1996-2010 (yd^3/year)	32,400	12,600	45,000

Notes:

Source: Statistics compiled by LRC from USACE, National Park Service, and Indiana DNR records.

[a] 25,637 in Spring 2003 + 26,661 in Fall 2003.

[b] Statistics from annual nourishment considered indicative of contemporary beach response. Earlier nourishments spaced at too great time intervals to be representative of annual response.

BOLD values used in summary Figure 28

Table 8 lists material dredged from the Portage/Burns Waterway, from Burns Waterway Harbor, and the NIPSCO BGS cooling water intake. Note that some of this sand was placed to the east at Beverly Shores, meaning it was backpassed. Table 8 is based on Plate 2 in USACE (2010), checked and modified as of May 2012 (reproduced in Appendix B).

Table 8. Dredging at Portage/Burns Waterway and Burns Waterway Harbor.

Project	Year	Vol. dredged (yd^3)	Offshore placement (yd^3)	Downdrift placement (yd^3)	Downdrift placement location	Updrift placement (yd^3)	Updrift placement location
Portage/ Burns Waterway and Burns Small Boat Harbor *	1985	59,000		59,000	Beach, NPS nourishment stockpile		
	1986	67,000		67,000	Beach at NPS		
	2000	143,000		143,000	Beach at NPS		
	2009	49,000		49,000	Nearshore, Og. Dunes		
Total *		318,000		318,000			
Portage, Small Boat annual 1985-2008		12,700		12,700			
Burns Waterway Harbor	1996	266,000*	234,000*	31,500*			
	2007	99,000	99,000				
	2008	55,000	55,000				
BGS Intake (NIPSCO dredges)	1980	275,000	275,000				
	1982	218,000				218,000	Beach, BGS
	1986	320,000		240,000	Nearshore, Og. Dunes	80,000	Nearshore, Beverly Shores
	1989	288,000		216,000	Nearshore, Og. Dunes	72,000	Nearshore, Beverly Shores
	1992	209,000		156,750	Nearshore, Og. Dunes	52,250	Nearshore, Beverly Shores
	1995	118,000		88,500	Nearshore, Og. Dunes	29,500	Nearshore, Beverly Shores
	1997	146,000		109,500	Nearshore, Og. Dunes	36,500	Nearshore, Beverly Shores
	1999	165,000		123,750	Nearshore, Og. Dunes	41,250	Nearshore, Beverly Shores
	2011	72,000**		72,000**	Nearshore, Og. Dunes		
BGS Intake (USACE	2006	30,000		30,000	Nearshore, Og. Dunes		

Project	Year	Vol. dredged (yd³)	Offshore placement (yd³)	Downdrift placement (yd³)	Downdrift placement location	Updrift placement (yd³)	Updrift placement location
dredges)	2007	228,000		228,000	Nearshore, Og. Dunes		
	2008	105,000		105,000	Nearshore, Og. Dunes		
	2009	110,000		110,000	Nearshore, Og. Dunes		
Total BGS 1980-2009 and Burns Waterway Harbor 2007-2008		2,366,000	429,000	1,407,500		529,500	
Annual average 1980-2009		78,900	14,300	46,900			
Total all dates		3,022,000	663,500	1,829,000		529,500	
Total annual average downdrift placement 1985-2009				73,200			
Annual ave. updrift placement 1980-2009						17,700	

Notes:

Source: USACE Chicago (2010), Plate 2, modified version May 2012, checked by LRC Operations Section, June 2012.

NPS = Placement at National Park Service beach (Portage Lakefront Pavilion) west of Portage/Burns Waterway

* = Not included in littoral transport calculations

** = Not included in 1980-2009 budget

BOLD values used in summary Figure 28.

7.2 Sediment volumes and budget

The cross-shore profiles and shorelines show that most of the shore west of the Mt. Baldy area has been approximately stable from the 1960s to the 1990s, with the exception of the fillet near the Arcelor-Mittal bulkhead. Figure 27 is a plot of profile volumes for CERC7, 8, 9, 10, 12, 15-1, 17-B, and SR16. The units are in ft³/ft, representing volume of sand for a strip of beach 1-ft wide above a specified base elevation. For most profiles, the base elevation used was -26.5 ft, but the actual base elevation is not important as long as it is below the zone of active sand movement on the shoreface. The important factor to consider is the difference in profile

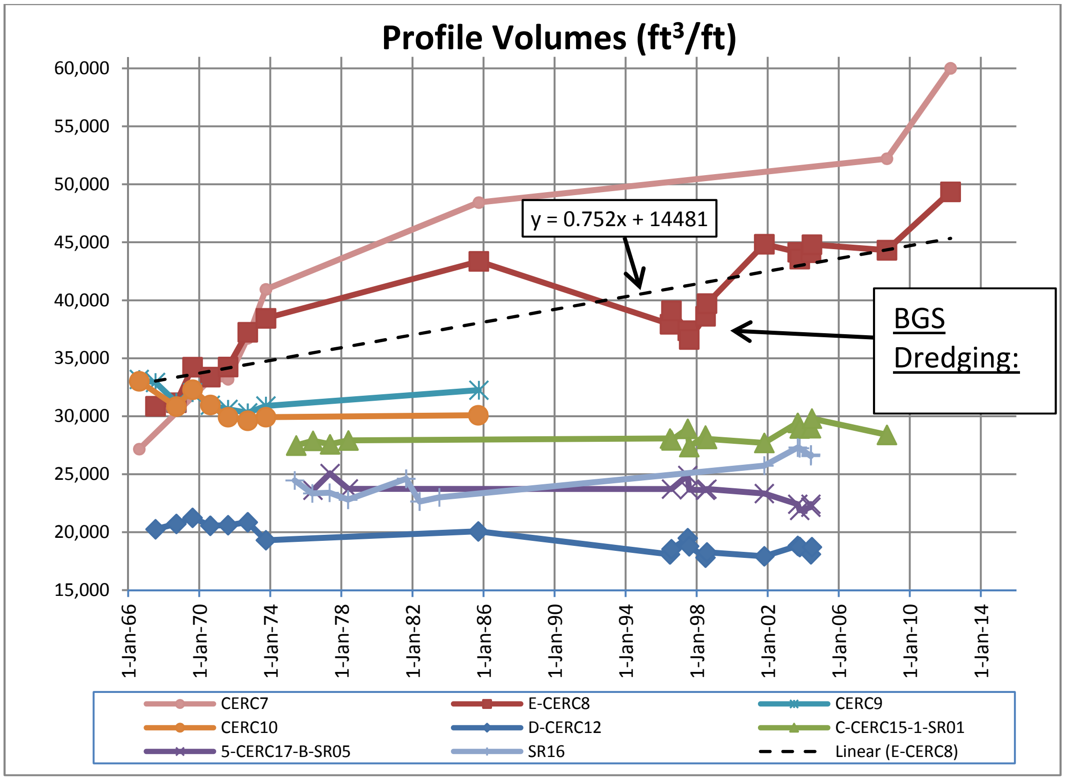

Figure 27. Profile volumes over time in ft^3/ft from 1966 to 2012. CERC9, 10, 12, 15-1, and 17-B are approximately horizontal, showing that the overall shoreface morphology has not changed significantly at these sites. CERC7 and CERC8-Line E rise upward with time, indicating the trapping and accumulation of sand on the east side of the Burns Waterway Harbor structure. 2012 survey data was available only at these two locations.

volume over time. CERC7 and CERC8-Line E show volume increase over four decades, documenting sediment trapping near the bulkhead. On the CERC8-Line E curve, the decrease in volume from 1992 to 1999 shows the dredging at the NIPSCO BGS cooling water intake. The dashed line is the linear trend for CERC8-Line E, showing a net increase in volume over the years even with dredging at the BGS intake.

To compute sediment accumulation in the fillet east of the Arcelor-Mittal bulkhead, we multiplied the increase in profile volumes at CERC7 and CERC8-Line E times the half-distances to the adjacent profile lines. The result provides an average annual accumulation of 115,000 yd^3 (19,700 + 95,300; see Table 9).

As shown in Table 8, total removal from Burns Waterway Harbor and the NIPSCO BGS intake between 1980 and 2009 was 2,366,000 yd^3. Annual average removal was 78,900 yd^3 (2,366,000 yd^3 ÷ 30 years).

Table 9. Increase in fillet sediment volume east of Burns Waterway Harbor (post-construction era 1966-2012).

	CERC7		CERC8-Line E
Volume annual (ft^3/ft/year)	583.4		274.7
Half distance CERC7 to E (ft)	862	Half distance E-D	8500
Dist. CERC7 to bulkhead (ft)	50	Half distance E to CERC7	862
Total distance multiplier (ft)	912		9362
Average annual vol. increase (ft^3/year)	532,049		2,572,195
Average annual vol. increase (yd^3/year)	19,700		95,300
Total annual increase fillet region (yd^3/year)		115,000	

Therefore, longshore sediment transport along this part of the Indiana shore is about 194,000 yd^3/year (115,000 + 79,000). This value excludes factors such as loss offshore to deep water (if any) or Aeolian loss or gain. This rate is higher than previous estimates.

Table 10 is a tabulation of flux, removal, and placement of sediment in the cell between Michigan City Harbor and Burns Waterway Harbor. This budget represents the era of sand accumulation in the fillet with minimal bypassing. The budget is based on the assumption 32,000 yd^3/year loss from the shoreline and dunes at Mt. Baldy. This value is reasonable because placement at Mt. Baldy has averaged 45,000 yd^3/year since the annual nourishment program began in 1996, and the beach and shoreface have stabilized. Sand now covers the shoreface, which was previously exposed clay. This is in contrast to the early decades of the 20th century, when the beach retreated many feet per year. The residual is only -200 yd^3, which means the budget is approximately balanced.

Figure 28 summarizes annual average fluxes, removals, and placements from the sediment cell extending from Michigan City Harbor to Burns Waterway Harbor. Averages are based on the 30-year period 1980-2009. Averages based on different time spans would result in different numbers. As stated above, the budget represents the era of sand accumulation in the fillet without a significant degree of bypassing. A future sediment budget will likely show the fillet semi-stable (less ΔV) but with higher volume of natural bypassing.

Sediment now is bypassing the Arcelor-Mittal bulkhead and entering the Burns Waterway Harbor entrance. This is a major change compared to the harbor's early years. In 1986, a side-scan sonar survey conducted by CERC

Table 10. Total sediment volumes, Michigan City to Burns Harbor cell, 1980s-2009.

Source or Loss	Data Source	Average Vol. (yd³/year)
Sediment inputs		
Placement Mt. Baldy (1996-2010) (P)	Dredge records	45,000
Michigan City Harbor bypassing	W.F. Baird & Assoc. (2004)[a]	99,400
Placement NPS and Beverly Shores (1980-2009) (P)	Dredge records	17,700
Mt. Baldy dune and shoreline loss (ΔV)	Assumption	32,000
Total input		193,300
Sediment losses		
Fillet growth at Arcelor-Mittal bulkhead (ΔV) [b]	Profile surveys	115,000
Removal from BGS intake (1980-2009) (R)	Dredge records	78,900
Other losses (Aeolian or offshore)	Assumption	0
Bypass around Arcelor Mittal bulkhead [b]	Assumption for 1980-2009	0
Total losses		193,900
Residual		-200

Notes:

[a] From W.F. Baird & Assoc. (2004) based on wave modeling

[b] This budget represents the era while sand was accumulating in the fillet, with minimal natural bypassing around the Arcelor-Mittal bulkhead.

showed the lake bed within the harbor to consist of clay with very little sand (Morang 1986). On the lake side of the breakwaters, the lakebed was clay with thin veneers of rippled sand.

A simple calculation can be used to estimate the amount of sediment bypassing the Arcelor-Mittal bulkhead. The 2010 shoreline is about 1000 ft from the origin of CERC7, and the length of the bulkhead is 2150 ft. In this area, profile CERC7 shows the active zone to be about -30 ft LWD. The -30 ft level on the 2008 Lidar profile is 3065 ft offshore, which is 915 ft beyond the north end of the bulkhead. Therefore, the proportion of the active zone beyond the bulkhead is 0.444 (915 ÷ 2065; see Table 11). The simplest assumption is that 44 percent of the transport is in the zone beyond the bulkhead, yielding about 86,000 yd^3/year (194,000 × 0.443). Longshore transport is not evenly distributed across the shoreface, and is greatest in the surf zone and close to the beach. But at this site, material may jet offshore in front of the bulkhead when waves approach from the north and northeast. The shoreline position has not changed greatly since 2005 (Figure 24), suggesting that excess sediment is wrapping around the end of the bulkhead and bypassing to the west.

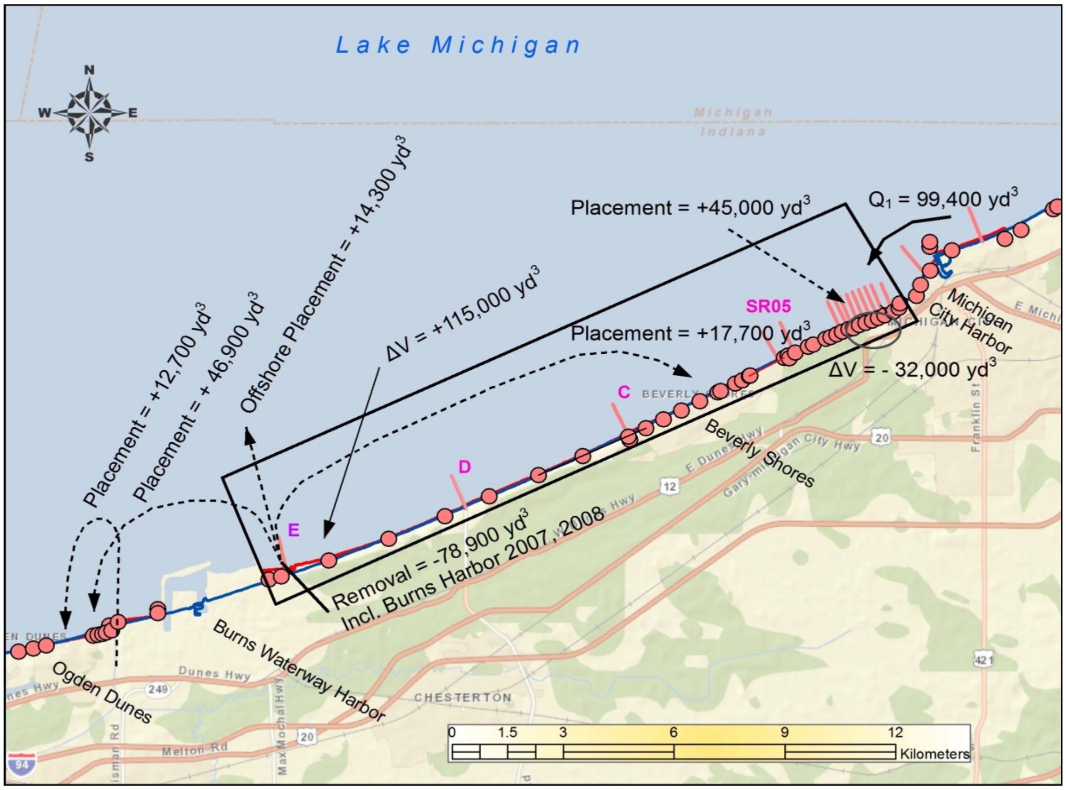

Figure 28. Average annual sediment accumulation at Burns Waterway Harbor fillet and removal for the post-harbor construction period. Volumes based on 1980-2009 era, 30-year average. This represents the era before major bypassing at the Arcelor-Mittal bulkhead. See text for details.

Table 11. Estimate of bypassing around Arcelor-Mittal bulkhead based on 2008 CERC7 profile.

Shoreline position 2010	1,000 ft
End of bulkhead	2,150 ft
End of active zone -30 ft LWD	3,065 ft
Width of active zone	2,065 ft
Active zone beyond bulkhead	915 ft
Proportion beyond bulkhead	0.443
Annual vol. bypassing (194,000 × 0.443)	86,000 yd^3/year

On Sunday, April 15th, 2012, at 17:15 CST, the M/V *American Integrity* ran aground when approaching Burns Waterway Harbor. The 1,000-ft vessel was loaded with iron ore pellets and drafted 26 ft 4 inches. The Master and crew were able to free the vessel and complete delivery to the harbor. Current NOAA charts indicated available depths between 30 and 47 ft in this area. This event supports the hypothesis that sand is wrapping around the end of the bulkhead and shoaling in the approaches to the Federal harbor.

7.3 Conclusions

After Burns Waterway Harbor construction in the 1960s, sediment accumulation in the fillet east of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead has averaged 115,000 yd^3/year. This is based on the change in volume measured at profiles CERC7 and CERC8-Line E from 1966-2012. Average annual dredging from the NIPSCO Bailly Generating Station (BGS) cooling water intake was 78,900 yd^3 for the period 1980-2009 (2,366,000 ÷ 30). Therefore, annual sediment moving by littoral transport to the west end of the Michigan City Harbor to Burns Waterway Harbor cell is about 194,000 yd^3 (115,000 + 78,900). This value exceeds previously published estimates for the Burns Waterway Harbor area.

The annual volume of sediment now bypassing the Arcelor-Mittal (Bethlehem Steel) bulkhead and entering Burns Waterway Harbor is about 86,000 yd^3. This is based on the proportion of the active profile that is now beyond the end of the bulkhead using the 2008 Lidar-based profile.

An average of 73,000 yd^3/year of material has been placed west of Portage/Burns Waterway (Burns Ditch) for the 1985-2009 period, with most placed in the water offshore of Ogden Dunes. This was derived from mechanical dredging around the NIPSCO Bailly Generating Station cooling water intake and from sand dredged from the Portage/Burns Waterway. Some sand was placed directly on the beach at the National Park Service Portage Lakefront Park property east of Ogden Dunes when the Burns Small Boat Harbor was under construction in 1985, and again when the Portage/Burns Waterway federal navigable channel was hydraulically dredged in 2000.

Full bypassing needs to be about three times the amount previously placed at Ogden Dunes if it is to match the longshore transport value of 194,000 yd^3/year.

If the entrance channel to Burns Waterway Harbor is dredged at a regular interval, these statistics will provide data to confirm the amount of material bypassing the Arcelor-Mittal bulkhead. In the future, we recommend the sediment budget be recomputed for a post-2009 scenario, one with limited fillet growth but with more sand bypassing the bulkhead and entering the federal harbor. If bathymetry or profile surveys show that the fillet profile is stable, then dredging at the BGS intake and in the mouth of Burns Harbor will account for almost all of the sediment carried by littoral currents to this

western end of the cell (with the assumption of minimal loss offshore to deep water).

We recommend that profile surveys be re-initiated at many of the original CERC locations to monitor shoreface conditions. Continuity of surveys will allow comparison with the historical data and will reveal changes in sediment volumes. In particular, surveys at CERC7 and CERC8-Line E will show if the fillet is continuing to grow or if it has stabilized. A re-analysis of offshore profiles and sediment placement at Mt. Baldy will help refine the amount of sand being eroded from that area. An examination of the shore between Michigan City and New Buffalo will provide more accurate volumes of sediment moving along the coast and bypassing Michigan City Harbor.

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Appendix A: Coordinate Information, Mt. Baldy Monitoring Program

Figures 29-35 are reproductions of figures showing coordinate information for the 1970s and 1980s Mt. Baldy monitoring program. Survey notes were supplied by Indiana DNR, originally provided by the USACE Chicago District to Purdue GLCRL.

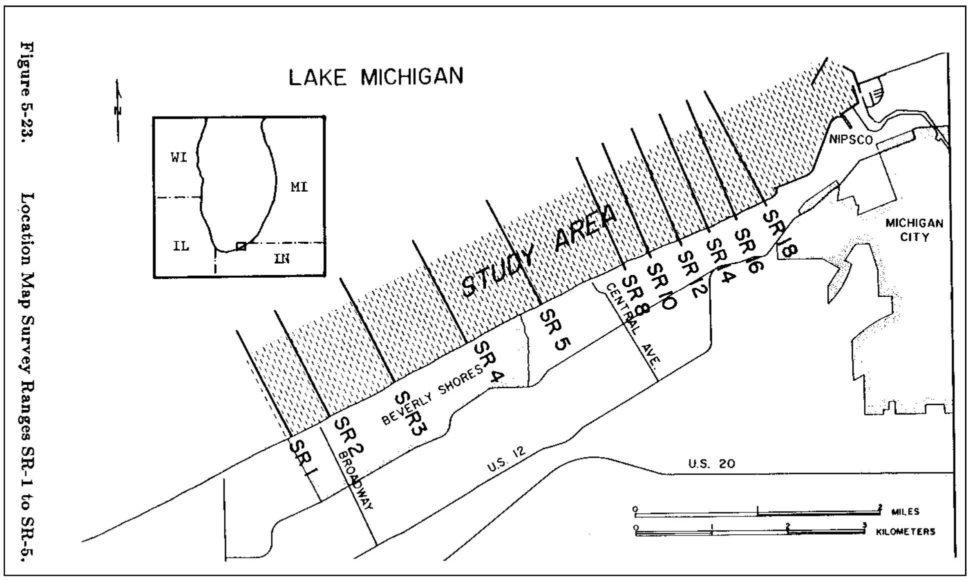
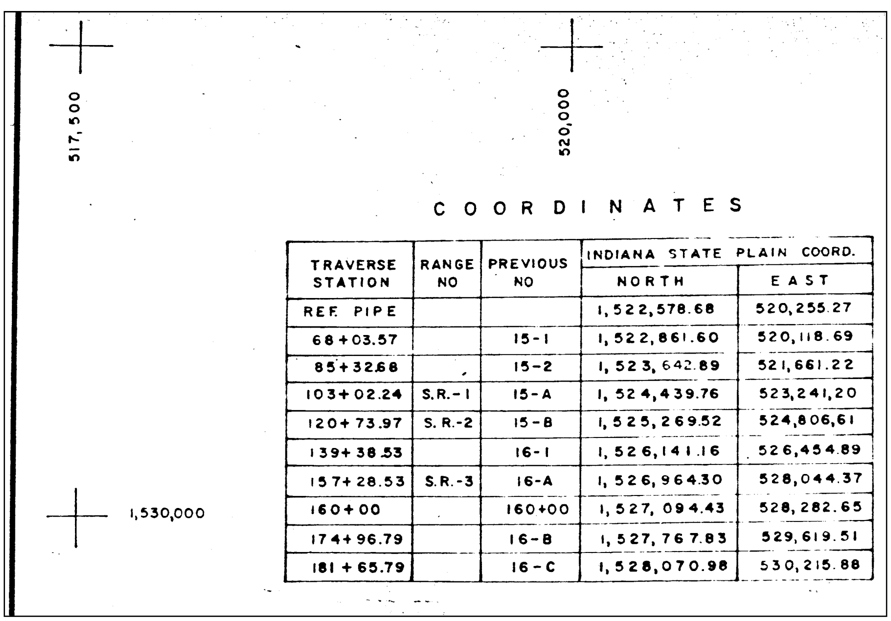


Figure 29. Survey locations near Mt. Baldy (from Wood and Davis 1986, p. 67).



COORDINATES

TRAVERSE STATION	RANGE NO	PREVIOUS NO	INDIANA STATE PLAIN COORD. NORTH	EAST
REF. PIPE			1,522,578.68	520,255.27
68+03.57		15-1	1,522,861.60	520,118.69
85+32.68		15-2	1,523,642.89	521,661.22
103+02.24	S.R.-1	15-A	1,524,439.76	523,241,20
120+73.97	S.R.-2	15-B	1,525,269.52	524,806,61
139+38.53		16-1	1,526,141.16	526,454.89
157+28.53	S.R.-3	16-A	1,526,964.30	528,044.37
160+00		160+00	1,527,094.43	528,282.65
174+96.79		16-B	1,527,767.83	529,619.51
181+65.79		16-C	1,528,070.98	530,215.88

Figure 30. Coordinate data for profile locations SR1-SR3 (CERC15-1 – 16-C).

COORDINATES

TRAVERSE STATION	RANGE NO	PREVIOUS NO	INDIANA STATE PLAIN COORD.	
			NORTH	EAST
190+00			1,528,501.00	530,930.72
224+47.79	S.R.-5	17-B	1,530,164.87	533,950.45
229+53.65		TRAV. PT.#1.	1,530,408.01	534,394.05
235+18.65	S.R.-6	18-1	1,530,646.86	534,906.08
247+86.66		18-2	1,531,182.91	536,055.21
252+87.49	S.R.-7	18-A	1,531,396.47	536,508.23
265+29.52			1,531,912.47	537,638.00
269+90.26	S.R.-8	18-B	1,532,089.21	538,063.49
275+91.24	S.R.-9	18-C	1,532,337.45	538,610.81
281+07.89	S.R.-10	18-D	1,532,550.52	539,080.60
287+73.18	S.R.-11	19-1	1,532,825.65	539,687.21
291+75.77	S.R.-12	0+00	1,532,934.25	540,074.88
297+75.60	S.R.-13	6+00	1,533,170.50	540,626.23
303+75.44	S.R.-14	12+00	1,533,392.76	541,183.37
309+75.27	S.R.-15	18+00	1,533,595.73	541,747.82
315+75.10	S.R.-16	24+00	1,533,840.85	542,295.28
321+74.93	S.R.-17	30+00	1,534,085.95	542,842.75
330+42.80	S.R.-18	R-2	1,534,408.80	543,648.33
336+42.70	S.R.-19	R-1	1,534,779.76	544,119.79
340+75.65		P. I. C.	1,535,200.78	544,220.73
356+95.65	S.R.-20	20-A	1,535,908.16	545,678.13
367+78.65			1,536,928.05	546,042.43
383+24.65	S.R.-21	20-B	1,538,219.37	546,892.49
LIGHT HOUSE			1,540,871.80	546,871.80
P. I. A.		P. I. A.	1,530,349.17	534,261.46
P. I. B.		P. I. B.	1,531,166.76	536,073.12
P. I. D.		P.T. NEAR 0+00	1,532,886.39	540,081.27
17-1	S.R.-4	17-1	1,528,466.76	530,847.49

1,535,000

Figure 31. Coordinate information for profiles SR4-SR21.

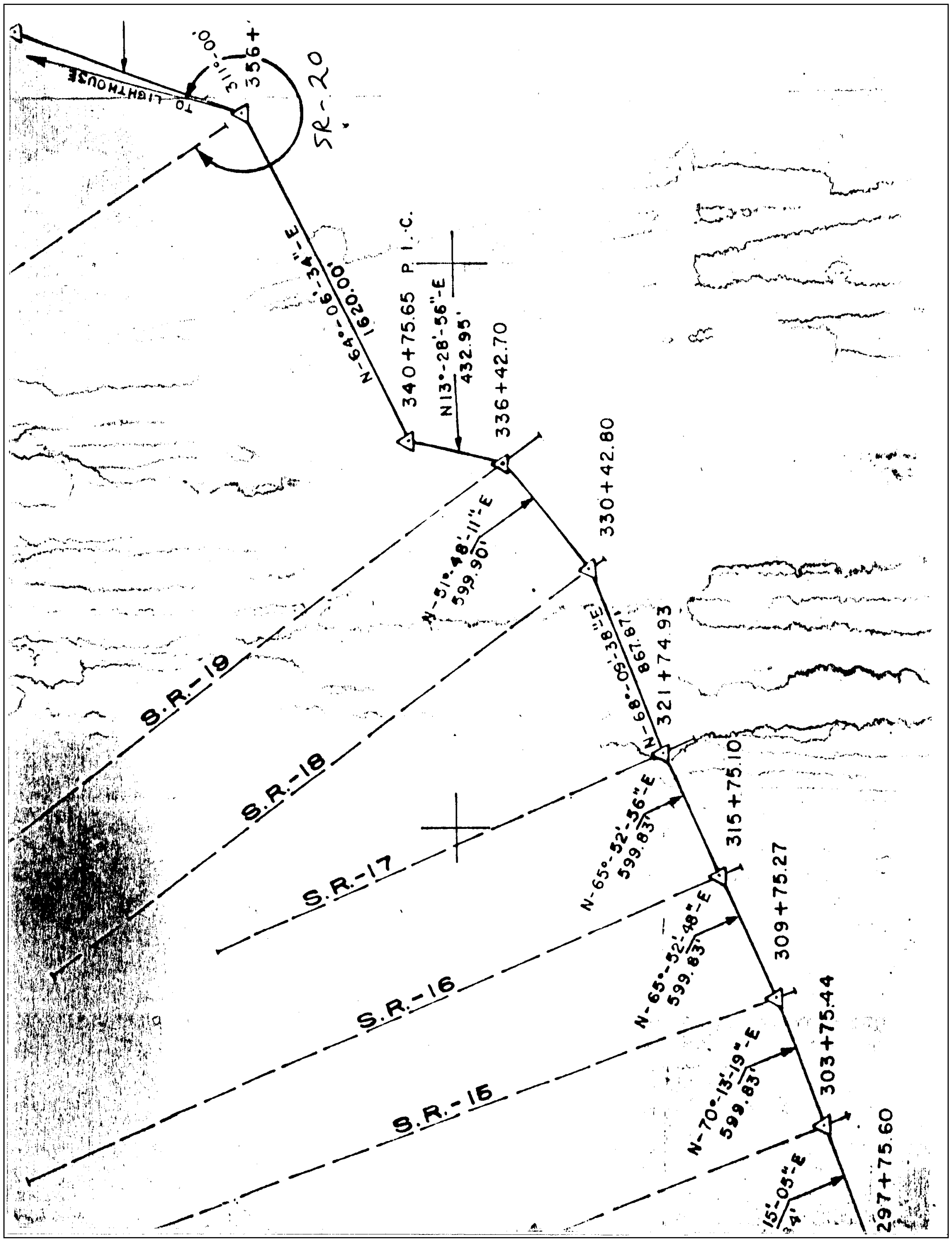


Figure 32. Survey notes for SR profiles. Figures supplied by Indiana DNR.

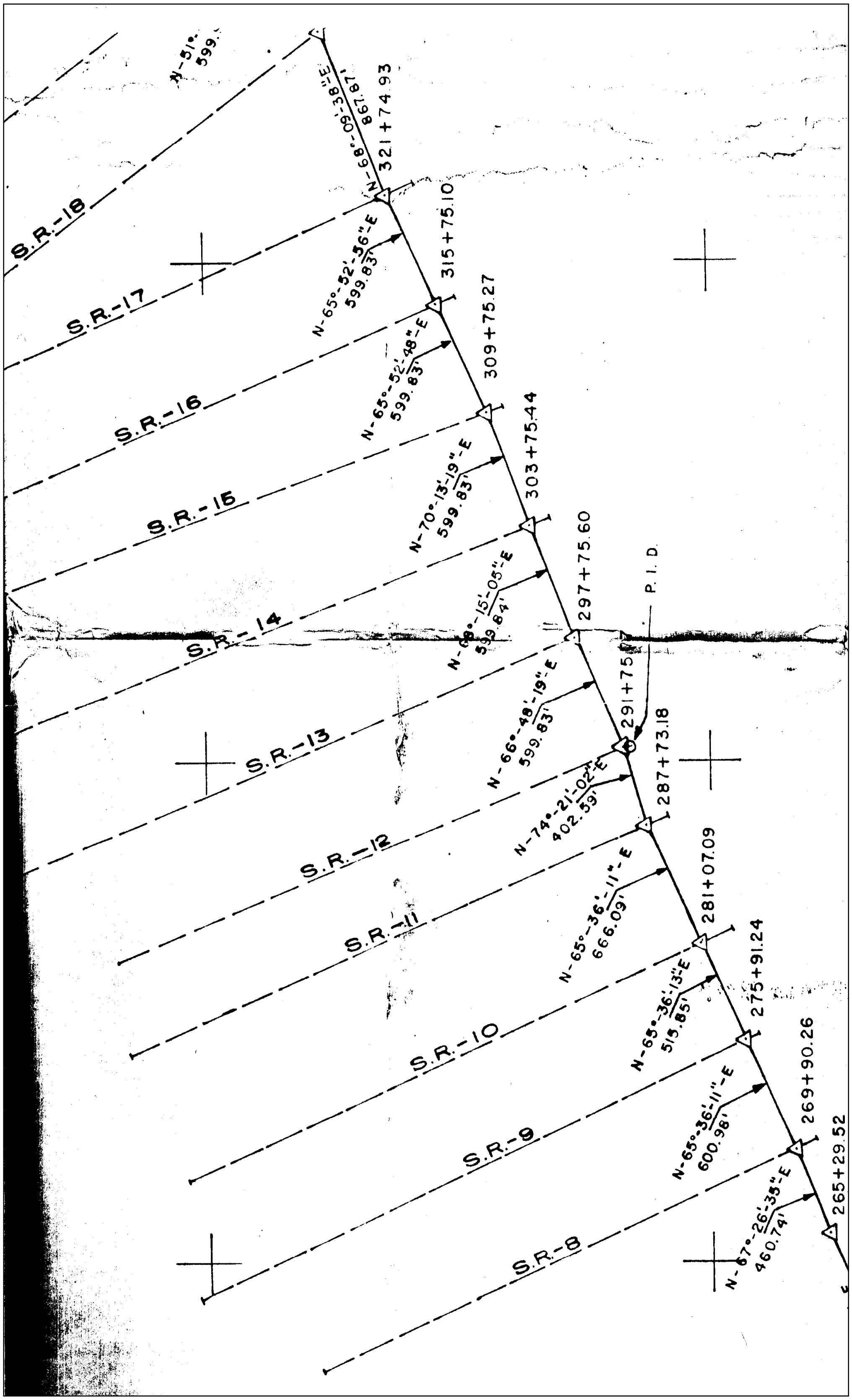


Figure 33. Survey notes, SR profiles.

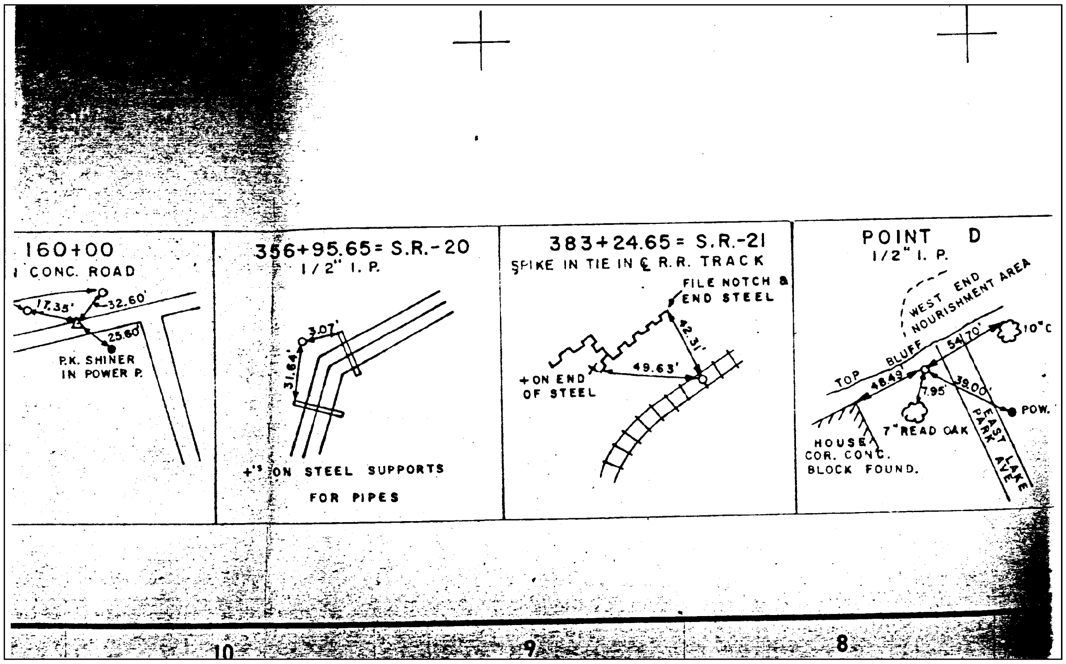


Figure 34. Survey notes for SR profiles.

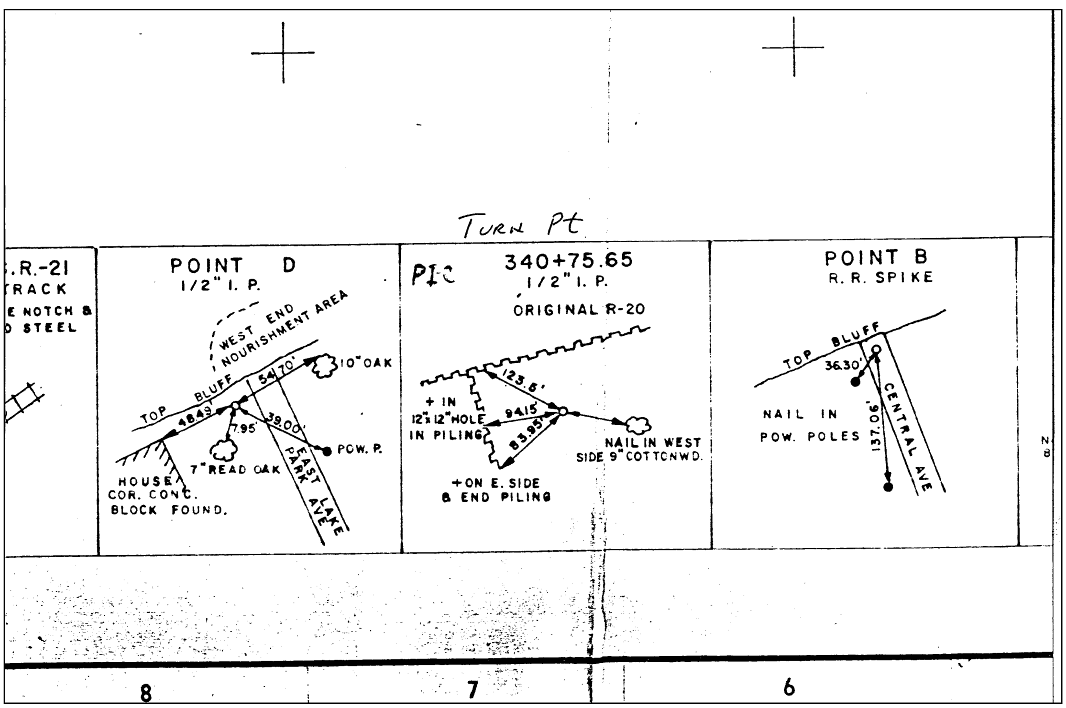


Figure 35. Survey notes for SR profiles, cont.

Appendix B: Dredging Volumes

Table 12 lists dredging volumes for Burns Waterway Harbor, Burns Small Boat Harbor, and the NIPSCO Bailly Generating Station (BGS) cooling water intake (May 29, 2012-modified version of Plate 2 in USACE Chicago, 2010). See Figure 28 for locations.

Table 12. List of dredging volumes from Burns Waterway Harbor and vicinity.

Project	Year	Amount Dredged (cu-yd)	Material Placement
Burns Waterway Harbor	2008	55,000	Open Lake Placement Area 'A'
	2007	99,000	Open Lake Placement Area 'A'
	1996	266,000	Open Lake Placement Area 'A'
Burns Small Boat Harbor	2009	80,000	Nearshore Placement Area 'B'
	2000	143,000	Beach Placement Area 'C'
	1986	67,000	Beach Placement Area 'C'
	1985	59,000	Beach Placement Area 'C'
NIPSCO Intake (USACE Dredges)	2009	110,000	Nearshore Placement Area 'B'
	2008	105,000	Nearshore Placement Area 'B'
	2007	228,000	Nearshore Placement Area 'B'
	2006	30,000	Nearshore Placement Area 'B'
NIPSCO Intake (NIPSCO Dredges)	1999	165,000	Nearshore Placement Area 'B'*
	1997	146,000	Nearshore Placement Area 'B'*
	1995	118,000	Nearshore Placement Area 'B'*
	1992	209,000	Nearshore Placement Area 'B'*
	1989	288,000	Nearshore Placement Area 'B'*
	1986	320,000	Nearshore Placement Area 'B'*
	1982	218,000	Shoreline at BGS
	1980	275,000	Unspecified Open Lake Placement

*NIPSCO 1986-1999 dredges placed 75% of the material nearshore at Ogden Dunes and 25% nearshore at Beverly Shores

Appendix C: Inventory of Indiana Cross-shore Beach Profiles

Table 13 is an inventory of 1960s and 1970s profiles digitized and replotted from Wood and Davis (1986) and 1996, 1997, 1998, 2001, 2002, and 2003 profiles recovered from various digital media. Figures 36-43 are plots of the profiles used in this study (not all digitized profiles were needed). The plots start at CERC7, next to Burns Waterway Harbor, and proceed east. The plots show the overall envelope of the data and list the dates used in the analyses.

Table 13. Cross-shore profile inventory, Indiana Shoreline, Lake Michigan.

Location (W to E)	15-Aug-66	15-Jul-67	15-Sep-68	15-Aug-69	15-Aug-70	15-Aug-71	22-Sep-72	1-Oct-73	16-Jun-75	26-May-76	12-May-77	25-May-78	24-Aug-81	28-May-82	7-Jul-83	24-May-84	29-May-85	27-Sep-85	1996pre	1996post	1997pre	1997post	1998pre	1998post	23-Oct-01	11-Sep-03	21-Oct-03	8-Jun-04	28-Jun-04
	Digitized from Wood and Davis (1986)																		From AutoCAD plot Files						From ASCII data files				
CERC1	X	X	X	X	X	X	X	X (bad)										X											
CERC2	X	X	X	X	X	X	X	X										X											
CERC3	X	X	X	X	X	X	X	X										X											
GLCRL1-WBR1																X	X												
GLCRL2-WBR2																X	X												
CERC4	X	X	X	X	X	X	X	X																					
GLCRL3-WBR3																X	X												
GLCRL4-WBR4																X	X												
CERC5	X (bad)	X	X	X																									
GLCRL5-WBR5																X	X												
CERC6_orig	X				X	X	X	X								X	X												
CERC6_new																													
CERC7	X				X	X	X	X										X											
CERC8	X (bad)	X	X	X	X	X	X	X										X											
E																			X	X	X	X	X	X	X	X	X	X	X
CERC9	X	X	X	X	X	X	X	X										X											
CERC10	X	X	X	X	X	X	X	X										X											
CERC11	X	X	X	X	X	X	X	X										X											
D																			X	X	X	X	X	X	X	X	X	X	X
CERC12		X	X	X	X	X	X	X										X											
CERC13		X	X	X	X	X	X	X										X											
CERC14								X										X											
C																		X	X	X	X	X	X	X	X	X	X	X	X
SR1_CERC15_A									X	X	X	X																	

Location (W to E)	15-Aug-66	15-Jul-67	15-Sep-68	15-Aug-69	15-Aug-70	15-Aug-71	22-Sep-72	1-Oct-73	16-Jun-75	26-May-76	12-May-77	25-May-78	24-Aug-81	28-May-82	7-Jul-83	24-May-84	29-May-85	27-Sep-85	1996pre	1996post	1997pre	1997post	1998pre	1998post	23-Oct-01	11-Sep-03	21-Oct-03	8-Jun-04	28-Jun-04
	Digitized from Wood and Davis (1986)																		From AutoCAD plot Files						From ASCII data files				
SR2_CERC15_B									X	X	X	X																	
SR3_CERC16_A									X	X	X	X																	
SR4_CERC17_1									X	X	X	X																	
5-GPS5																				X	X	X	X	X	X	X	X	X	X
SR5_CERC17_B									X	X	X	X																	
SR6_CERC18_1																			X		X		X	X	X	X	X	X	X
SR8_CERC18_B									X	X	X	X	X	X	X			X											
SR10_CERC18_D									X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X
SR11_CERC19_1																									X	X	X	X	X
SR12_0+00									X	X	X	X	X	X	X			X							X	X	X	X	X
SR13_6+00																			X	X	X	X	X	X	X	X	X	X	X
SR14_12+00									X	X	X	X	X	X	X			X							X	X	X	X	X
SR15_18+00																									X	X	X	X	X
SR16_24+00									X	X	X	X	X	X	X			X							X	X	X	X	X
SR17_30+00																			X	X	X	X	X	X	X	X	X	X	X
SR18_CERC_R2									X	X	X	X	X	X	X			X							X	X	X	X	X
SR19_CERC_R1																													
SR20_CERC20_A																													
B																			X	X	X	X	X	X	X	X	X	X	X
SR21_CERC20_B																													
A																			X	X	X	X	X	X	X	X	X	X	X

Notes:

Dates for 1966-1985 surveys may vary by several days from date on header.

Exact dates unknown for 1996, 1997, and 1998 surveys; assumed to be mid-summer. Data were extracted from AutoCAD plot files.

Not all profiles dates and locations were used in the Burns Harbor sediment budget analysis

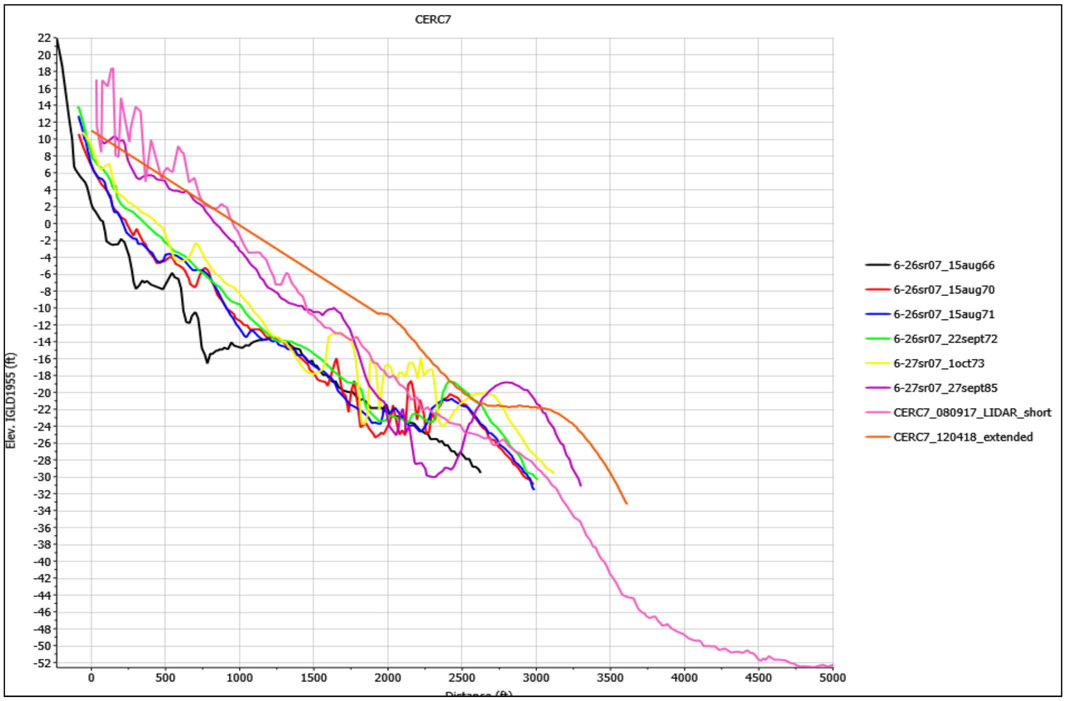


Figure 36. CERC7, about 50 ft east of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead. No profile surveys were made after 1985; the 2008 profile was cut from Lidar data and the 2012 profile from acoustic bathymetry (survey boat) data. The 2012 data began 1932 ft offshore of CERC7 but was extended onshore with a straight-line segment.

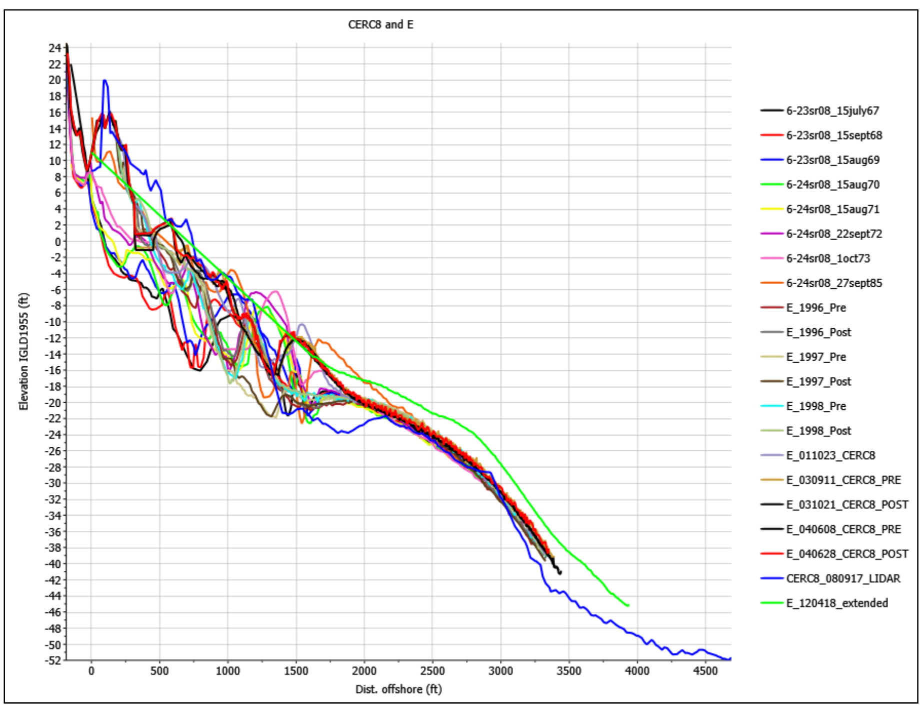


Figure 37. CERC8 and Line E, located east of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead. This was the most complete dataset in this study. CERC8 is located at the northwest corner of the NIPSCO BGS outfall canal building. The 2012 profile was cut from acoustic bathymetry survey data. The 2012 data did not start until 1,615 ft offshore of the CERC8-CERC9 baseline (see text).

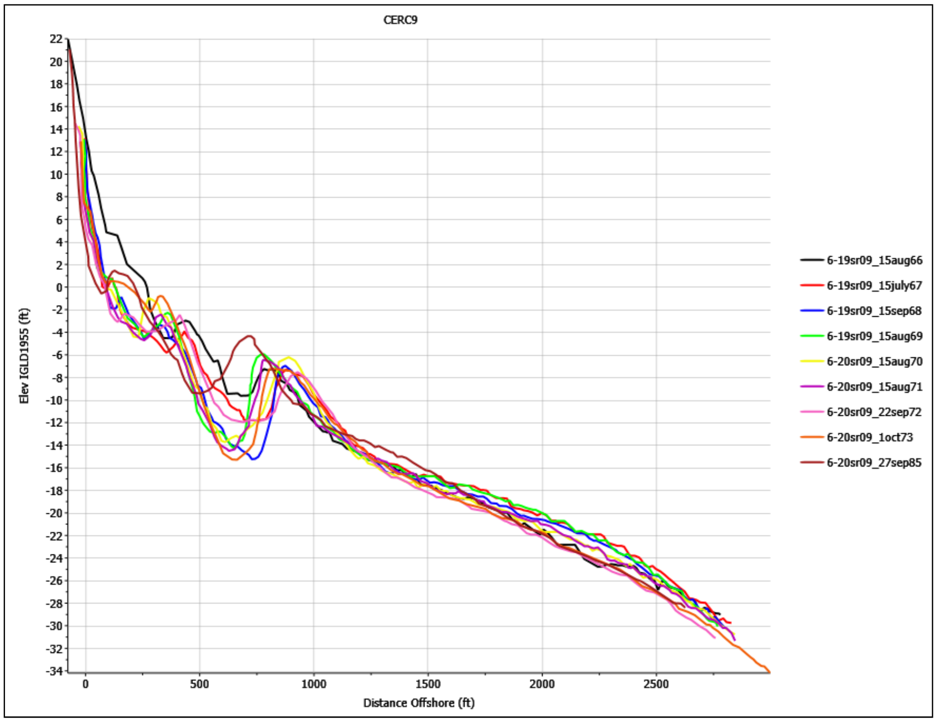


Figure 38. CERC9. No surveys later than 1985 were available for this site and the 2008 Lidar data could not be used. CERC9 is located immediately west of the Town of Dune Acres on a natural shoreline

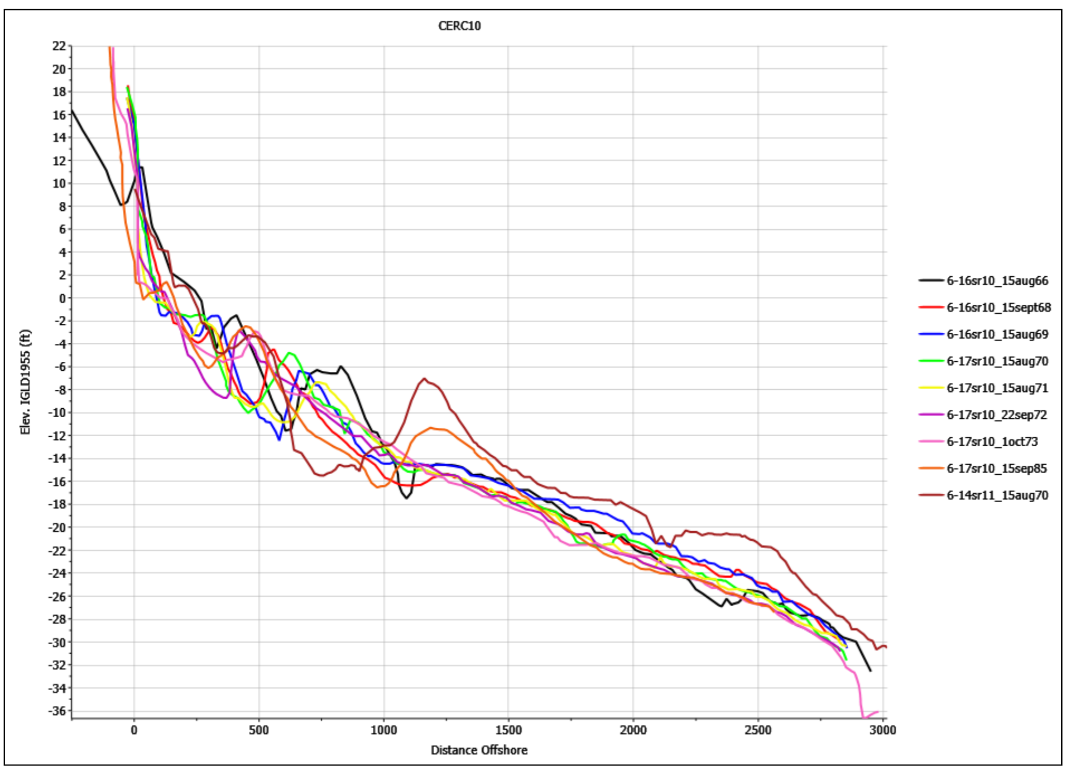


Figure 39. CERC10. No surveys later than 1985 were available for this site. CERC10 is located within the Town of Dune Acres on a protected shoreline

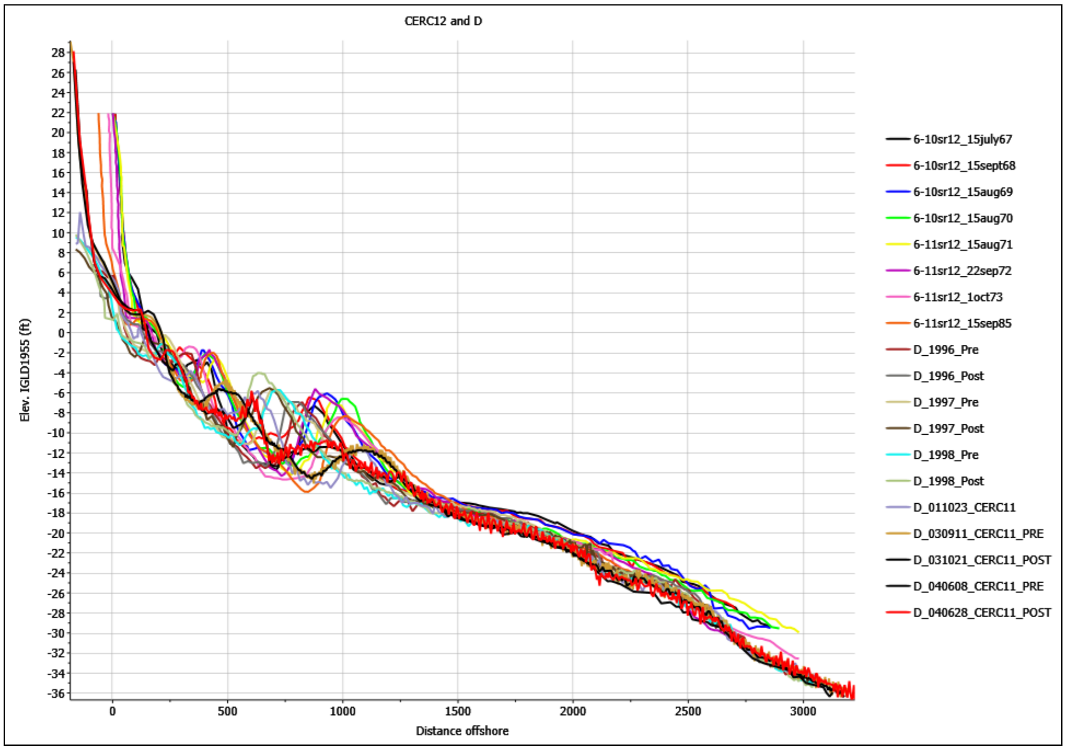


Figure 40. CERC12 and Line D. CERC12 is located near the west end of the Indiana Dunes State Park on a natural shoreline

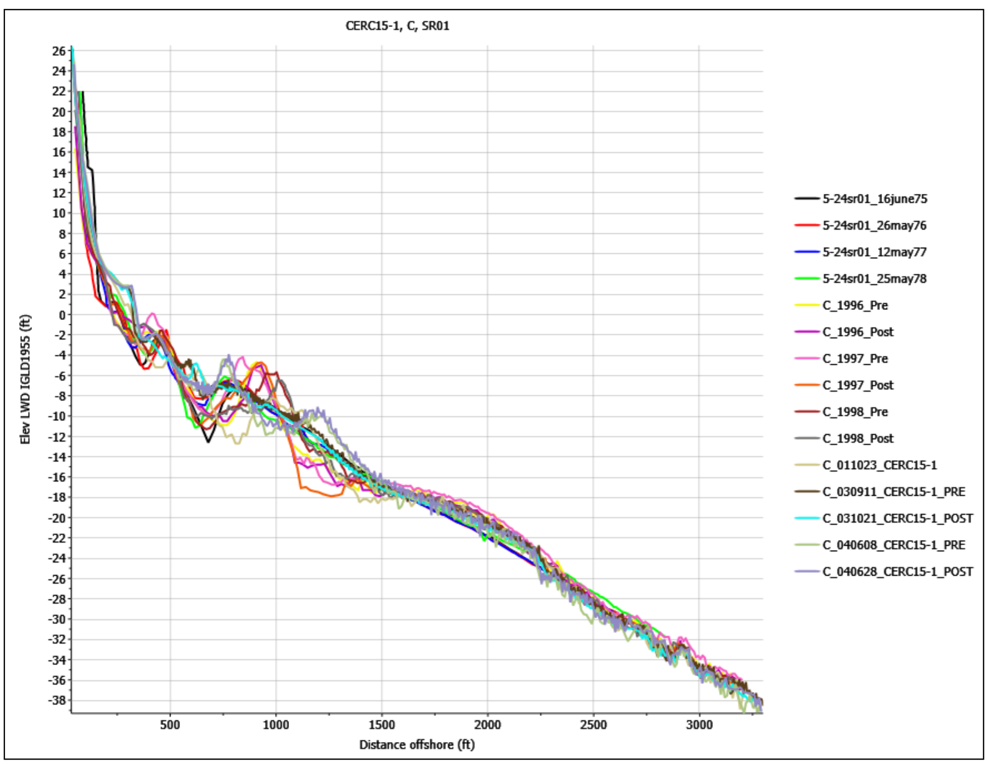


Figure 41. CERC15-1 (SR01) and Line C. CERC15-1 is located at Kemil Road, that separates the east end of Indiana Dunes State Park from the west end of Beverly Shores

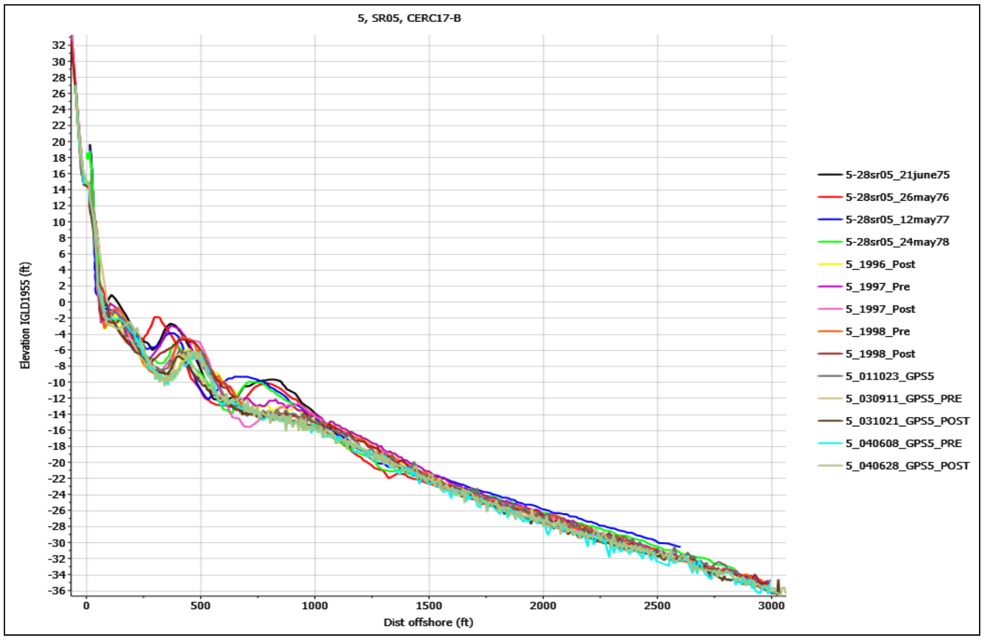


Figure 42. CERC17-B (SR05) and Line 5 (GPS5). CERC17-B (SR05) is located at the east end of Beverly Shores on a protected shoreline

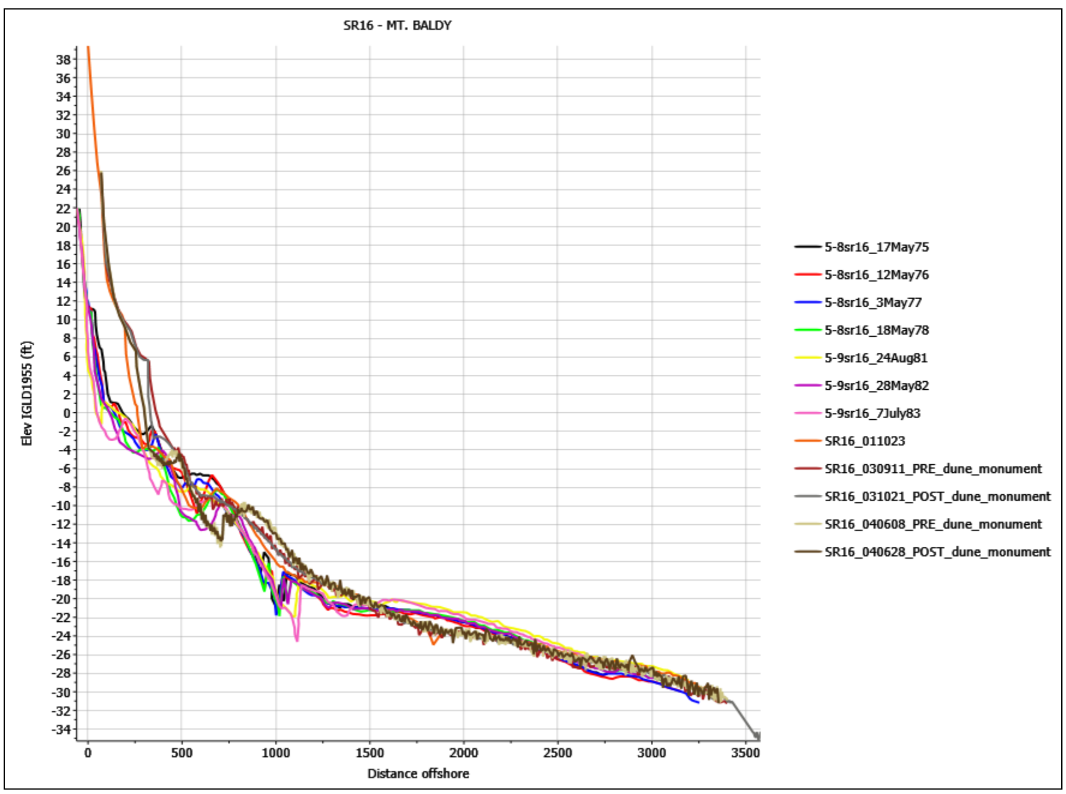


Figure 43. SR16 at Mt. Baldy. SR16 is located near the east end of the first two 1974 and 1981 quarry derived beach nourishments that were placed between survey lines SR12 and SR17. SR16 now defines the western boundary of the deposition site for approved quarry derived beach nourishment material for the 1996 to present (2012) placements by the USACE. The upper profiles that extend farthest lakeward (approx. elevation 8-10 ft) represent the newly created wide beach that presently protects the natural Mt. Baldy dune from erosion.

REPORT DOCUMENTATION PAGE

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Reviewed by Jeffrey Waters, Linda L. Lillycrop, and Stephen Davis (IN DNR).

14. ABSTRACT
Net sediment transport in the littoral cell extending from Michigan City Harbor to Burns Waterway Harbor, IN, is from east to west. For the four decades following construction of the harbor (approximately 1966-2010), net littoral transport averaged about 194,000 yd^3/year (115,000 + 79,000). Of this amount, accumulation in the fillet east of the Arcelor-Mittal (formerly Bethlehem Steel) bulkhead was about 115,000 yd^3/year. These results are based on analysis of cross-shore beach profiles, reprocessed from paper records and electronic files. Dredging from the NIPSCO Bailly Generating Station cooling water intake was 79,000 yd^3/year (2,366,000 yd^3 ÷ 30 years). The total transport calculated in this study is higher than most published previous estimates.

The volume of sediment now bypassing the lakeward end of the bulkhead and entering the Federal harbor is estimated to be 86,000 yd^3/year. This value is based on the proportion of the active zone beyond the lakeward (northern) end of the Arcelor-Mittal bulkhead (194,000 × 0.443). This value will have to be confirmed with dredging statistics in the future.

A ship grounding in April, 2012, demonstrated that the approach channel east of Burns Waterway Harbor is significantly shallower than shown on hydrographic charts. This supports the hypothesis that significant sand is bypassing the lakeward end of the Arcelor-Mittal bulkhead rather than being trapped in the fillet.

An average of 73,000 yd^3/year of sand has been placed west of Portage/Burns Waterway (Burns Ditch) (1,829,000 total from both the fillet and the Portage/Burns Waterway ÷ 25 years). Most sand has been placed in shallow water offshore of the town of Ogden Dunes, and some was placed directly on the beach at the National Park Service Portage Lakefront Park property. Full bypassing needs to be about three times this amount if it is to match the longshore transport value of 194,000 yd^3/year.

15. SUBJECT TERMS

	Burns waterway harbor	Sediment budget
Aerial photography	Lake Michigan	Sediment volumes
Beach profiles	Michigan city harbor	Shoreline mapping

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